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Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION

MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

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PROJECT APOLLO

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By Michael E. Donahoo and Charles W. Fraley
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EVASIVE MANEUVER SUBSEQUENT TO CSM/LM EJECTION

FROM THE S-IVB IN EARTH ORBIT

By Michael E. Donahoo and Charles W. Fraley

SUMMARY

The following analysis and data are documented to record the analysis conducted and the procedures recommended for the Apollo 9 mission (ref. 2). Additionally, this documentation will be applicable as a basis for future missions which are earth orbital either in the nominal or alternate mission category.

The analyses conducted which led to the development of the Apollo 9 evasive maneuver subsequent to CSM/LM ejection will be reconstructed step by step to provide an understanding of the final results. This reconstruction can then be used for planning purposes which might arise for future missions. The resultant recommendation precluded recontact between the CSM/LM and S-IVB during the actual Apollo 9 mission.

The recommended sequence of postejection events also applied to contingencies involving S-IVB and service propulsion system (SPS) ignition failures and covered a range of S-IVB vent magnitudes. The recommended sequence also adequately provided for earlier than nominal S-IVB ignition in the ascent-to-orbit phase of the mission.

INTRODUCTION

The nominal CSM/LM separation from the S-IVB was accomplished with a four-spring system mounted on the S-IVB. These four springs ejected the CSM/LM from the S-IVB. However, while the CSM/LM was ejected during the Apollo 9 mission (ref. 2), the S-IVB would undergo a continuous hydrogen propulsive vent which would accelerate the booster along its +X-axis and in the direction of the ejected CSM/LM. Previous analysis indicated that ejections performed during the PV would result in recontact with the S-IVB at approximately 235 seconds after ejection initiation (ref. 1). Two techniques can be defined that eliminates the close-in recontact problem. Either the S-IVB PV can be commanded off during ejection, or an evasive maneuver can be performed subsequent to ejection and prior to the period of the recontact problem.

The first technique involves inhibiting of the S-IVB PV. The PV inhibit technique is undesirable because the booster propellants could become unsettled; therefore, development of an acceptable evasive maneuver is the subject of the remaining discussion.

SYMBOLS AND DEFINITIONS

ARIA	Apollo range instrumention aircraft
CAR	Carnarvon tracking station
CSM	command and service modules
CSM/LM	CSM and LM in the docked configuration
daylight	nominal ejection time at 2 minutes into daylight
ejection	CSM/LM separation from the S-IVB
g.e.t.	ground elapsed time from lift-off
HAW	Hawaii tracking station
LM	lunar module
LH	local horizontal
LV	local vertical
PV	continuous propulsive vent
RCS	reaction control system
SLA	spacecraft/LM adapter
SC	spacecraft
SM	service module
SPS	service propulsion system
SPS-1	first SPS burn
S-IVB	third stage of the Saturn V launch vehicle

T&D transposition and docking

TLI translunar injection

MANEUVER CONSTRAINTS

For the development of an acceptable maneuver involving a minimum of time and effort, it becomes necessary to establish all constraints prior to any analysis. These constraints are enumerated in table I and are defined as follows.

Minimum Reaction Control System (RCS) Burn Time

The recommended maneuver will be selected to minimize the RCS fuel usage without violating other constraints.

Minimize Maneuvering

Maneuver simplicity is desirable. The recommended maneuver will involve the least amount of SC maneuvering possible from the time of ejection until the time of the evasive burn. This will include ejecting, orienting to the nearest attitude which satisfies the constraints, and performing one SC evasive burn.

Eliminate Lift-Off Date Dependency

The maneuver will be constructed so that a reasonable delay in the lift-off date will not require development of a completely new evasive maneuver. To test for such flexibility, the recommended maneuver should be simulated with a range of possible ejection attitudes. This constraint was fully utilized for the Apollo 9 mission when the lift-off date was shifted several months from the time the analysis was applicable. This required a minimum of verification in order to establish the validity of the maneuver for the new launch date.

Minimum Separation Range

The criteria for avoiding close-in recontact requires that the separation distance between the CSM/LM and the S-IVB increases monotonically to 100 feet subsequent to ejection. This distance must be maintained as the minimum closest approach distance. The recontact region can be considered as a sphere with a radius of 100 feet with the S-IVB c.g. as the center of the sphere (fig. 1).

Separation Distance At S-IVB Reignition

The separation distance between the CSM/LM and S-IVB must be at least 500 feet at the time of S-IVB reignition. This range was chosen to avoid any detrimental effects of the S-IVB J-2 plume on the CSM/LM if the CSM/LM were located directly behind the reigniting S-IVB.

Maximize Separation Distance

The separation range during the time from ejection plus 20 minutes to ejection plus 35 minutes should be maximized but must remain compatible with other constraints. This time span was selected for the Apollo 9 mission because it occurs from daylight through HAW which was the most probable time of ejection. The range should be maximized to decrease debris impact probability in the event of an S-IVB explosion at ignition.

Lateral Position at Ignition

The CSM/LM should not be in a lateral position to the S-IVB at the time of S-IVB ignition (fig. 2). As in the previous constraint, the purpose of this constraint is to protect the CSM/LM from the probable debris impact area of an exploding S-IVB. The only presently available information indicates that for an S-IVB explosion the resulting debris travels in a direction normal to the longitudinal axis of the S-IVB. Therefore, avoidance of this lateral area will lower the debris impact probability.

Minimize Time In Lateral Area

An explosion could occur in the S-IVB as a result of increased fuel tank pressures. The monitoring of these tank pressures from the CSM is terminated at CSM S-IVB separation. After this time a tank pressure reading can only be taken when the S-IVB is over a ground station. Therefore, the time the CSM/LM is in a position lateral to the S-IVB while not in ground station coverage should be minimized.

Recontact For No S-IVB Reignition Second

The recommended maneuver should not contain long-range recontact possibilities if the S-IVB first reignition can not be performed. The following contingency cases could be analyzed for recontact.

1. With no first S-IVB reignition and with the subsequent SPS-1 and the second S-IVB reignition.

2. With no first S-IVB reignition or no SPS-1 burn and with the S-IVB contingency burn.

3. With no S-IVB burns and with SPS-1 initiated.

SM RCS Thruster Burn Constraint

LM thermal constraints are such that the SM RCS-X thrusters cannot fire continuously for longer than 7 seconds while in the docked configuration. Therefore, the RCS evasive burn time is limited if the SM -X thrusters are to be used.

S-IVB Local Horizontal Command

On the nominally planned Apollo 9 mission the inhibit was to be released over HAW, subsequent to ejection. This allowed the S-IVB to go from its inertial hold attitude profile to a local horizontal attitude. This attitude was maintained in the orbit rate mode. Also, an S-IVB failure to orient to the local horizontal was considered.

Mandatory S-IVB Data Requirements

For the Apollo 9 mission, data requirements from the S-IVB necessitated S-IVB ground coverage at ejection. This indicated that only ejection opportunities over CRO, daylight, and HAW would be considered. Additionally, contingency ejection times other than those previously listed were analyzed. Therefore, the nominal evasive maneuver was recommended to be used for continuous ejection opportunities between stations.

ANALYSIS

The following section concerns the analyses performed to support the Apollo 9 mission. This section is divided into two major groups. The first group concerns the nominal mission as described at the time analyses were begun. Small dispersions about the nominal was included for completeness. The second section concerns the contingency analysis for failures, systems changes, and perturbations to the Apollo 9 mission which evolved during the planning phase of the mission.

NOMINAL MISSION

The nominal Apollo 9 mission profile indicated that the actual ejection would be performed approximately 2 minutes into daylight over an ARIA (fig. 3). Following separation the S-IVB would be oriented to a local horizontal attitude over HAW and ignition of the second burn would occur at approximately 4 hours 45 minutes into the mission.

The first step in determining the maneuver involved establishing the direction in which the CSM/LM would maneuver after ejection. To eliminate an infinite number of candidate maneuvers, the orbital period of the CSM/LM should be changed so that greater separation distances are generated. The evasive maneuver must be and was planned to be performed inplane for the Apollo 9 mission. Further, the maneuver was constrained to be performed in the local vertical for simplicity. The following is a discussion of maneuvers performed both up and down along the local vertical.

Pitch-down Maneuver

The pitch-down maneuver was defined as the ejection of the CSM/LM from the S-IVB and the pitching of the SPS engine bell below the local horizontal. This orientation was in the opposite direction as shown in figure 4. The SM RCS -X thrusters were used to perform the evasive maneuver.

The first consideration was to avoid close-in recontact problems. Figure 5 presents the results obtained by orienting the CSM/LM at varying pitch-down angles relative to its attitude at ejection. A pitch-down of 40° with a 3-second RCS burn initiated at ejection plus 150 seconds avoids recontact while the 20° maneuver definitely results in recontact. In these close-in simulations a 15-pound PV for the S-IVB was considered a worst case. Data from previous missions and vent data for the Apollo 9 mission indicated that a vent from 9 to 12.5 pounds could be expected at ejection.

Pitch-up Maneuver

The pitch-up maneuver was performed in the direction indicated in figure 4. The value for the orientation angle is measured in degrees from the ejection attitude and their effect is presented in figure 6. The 2-second evasive maneuver initiated at ejection plus 150 seconds (the burn time for all cases unless otherwise stated) resulted in recontact even for maneuvers up to 90°. However, in a 3-second burn, any recontact (close-in) was avoided for orientations as small as 50°.

Pitch-up Versus Pitch-down

The analysis to this point indicates that in a pitch-down of 40° or a pitch-up of 50° coupled with a 3-second evasive burn recontact was avoided. The minimum maneuvering constraint indicates that the pitch-down was, therefore, superior. However, figure 7 indicates that more constraints were violated by the pitch-down maneuver for long-range considerations than for the pitch-up maneuver. Weighing the undesirability of spending more time in the lateral zone as opposed to the undersirability of maneuvering an additional 10° the pitch-up maneuver was most desirable.

As this point in the analysis, the orientation to the evasive attitude will be in the direction shown in figure 8. The maneuver will begin as soon after ejection as possible, when the LM footpads have sufficiently cleared the booster, and the evasive burn will be initiated at ejection plus 150 seconds.

Additional cases were analyzed for the pitch-up type maneuver in which the orientation angle and evasive ΔV were varied. These results are presented in figures 9(a) through 9(c). Although in most instances the RCS burn time violates the docked thermal constraint of the LM, the figures do serve the purpose of indicating the trend resulting in a variation of evasive maneuver parameters.

Nominal Procedure - December 1968 Launch

The previous analyses have indicated that the maneuver outlined in table II was acceptable from the standpoint of recontact for a 15-pound S-IVB PV with ejection occurring over ARIA. For certain reasonable delays, it is conceivable that ejection might have occurred over CRO, ARIA, or HAW. The above sequence is than applied to ejections over the above facilities and the resulting relative motion is presented in figures 10(a) and 10(b) for the close-in and long-range considerations,

respectively. No recontact problems existed and the constraints were satisfied for each discrete ejection opportunity. However, the lateral position constraint at the time of S-IVB reignition would have been violated if the ejection had occurred at some specific time between ARIA and HAW. Futher analysis showed that this constraint could be eliminated by applying additional RCS burn time.

The following analysis concerning the nominal procedure for an Apollo 9 December 1968 launch was evaluated to determine the effects of vent magnitudes, doing a SC pitch rather than local vertical pitch, S-IVB local horizontal command and lift-off date (T&D attitude).

Nominal procedure - vent variations.- Figures 11(a) and 11(b) present the results of simulating the procedure defined for Apollo 9 with a variation in the S-IVB PV magnitude. As previously stated, the expected vent magnitude was between 9 and 12.5 pounds. However, to account for small dispersions and unplanned occurrences the vent was varied from zero to 15 pounds in 5-pound increments. As expected, the larger vents resulted in the CSM/LM moving behind the S-IVB more quickly. Also, because the orbital segment considered had the vent in a posigrade direction, the S-IVB continually added energy to the S-IVB orbit. This resulted in the CSM/LM passing below and ahead of the booster. Therefore, the larger the vent the more quickly the SC goes below and in front of the S-IVB. The results [figs. 11(a) and 11(b)] indicated that the proposed maneuver was free of any recontact areas for the nominal sequence for the close-in and long-range considerations. Also, the maneuver constraints were satisfied except for special vent magnitudes (i.e., approximately 14 lb for ARIA ejection).

The effect of vent variations was also simulated for the nominal procedure with the increase of the RCS evasive burn from 3 to 6 seconds. As expected, the close-in separation distance was increased (fig. 12). The effect on the long-range separation parameters was for the CSM/LM to initially go higher above the S-IVB and remain above for a longer period of time. The lateral constraints were relieved by the additional ΔV and no recontact resulted from the vent variations. These effects were beneficial but the merits do not compensate for the additional RCS fuel consumed. Therefore, the 3-second burn sequence outlined in table II was retained.

Nominal procedure - LH command.- A failure to release the inhibit allowing the S-IVB to orient the LH attitude induced some variations in the relative motion. This inhibit failure was simulated for the 3-second RCS nominal procedure with 15-pounds S-IVB vent force and the relative motion displayed in figure 13. The long-range separation components undergo noticeable changes but the effects are not significant from the standpoint of recontact. Therefore, an inhibit release failure was of minor concern.

Nominal procedure - roll effect.- At the time of orientation initiation to the evasive burn attitude the SC had some roll in attitude with respect to the local horizontal. Figure 14 presents a comparison of relative motion if the crew had performed the pitch-up maneuver about the SC Y-axis (roll -60°) rather than the recommended pitch-up along the local vertical (roll 0°). The effect was essentially negligible with respect to problems of recontact. Also, the SC pitch would probably consume less fuel because the SC is maneuvered about one axis rather than two axes.

Nominal procedure - lift-off date.- To fulfill all maneuver constraints the proposed sequence should apply to all launch dates other than those previously planned. Figure 15 indicates that a wide range of T&D attitudes also had an insignificant effect on the relative motion. Actually, the attitudes used in generating figure 15 cover a much wider range than was experienced on any lift-off date for Apollo 9, although the results indicate the insignificance of the lift-off date on the relative motion.

Nominal procedure - February 1969 launch.- All the previous data generated for the scheduled December 1968 launch should have been applicable to the February 28, 1969 launch date. Although pertubations in the previous simulations indicated that this was true, sample check cases were simulated and the relative motion presented. The check cases were an evaluation of the nominal procedure as outlined in table II with the orientation along the local vertical. RCS burn times of 3 and 6 seconds were simulated over CRO, daylight, and HAW. The results of each are discussed in the following.

Nominal procedure - CRO.- The nominal evasive sequence was simulated, assuming that ejection would occur over CRO, employing either the 3- or 6-second RCS burn. The relative motion for each is presented in figures 16(a) and 16(b), respectively, which also show the effect of varying the vent force from zero to 15 pounds. Relative motion and position at the time of the first S-IVB reignition indicated that the maneuver was still adequate.

Nominal procedure - daylight.- Figures 17(a) and 17(b) present the relative motion experienced when ejection was performed at nominally planned time. The 3-second evasive burn placed the CSM/LM in a lateral position below the S-IVB at the time of reignition for a 15-pound vent. However, the 6-second evasive burn elimated this problem and produced satisfactory relative motion for all vent magnitudes.

Nominal procedure - HAW.- The 3- and 6-second evasive burns did not violate any maneuver constraints for the range of vent magnitudes considered if ejection was performed over HAW.

CONTINGENCIES AND SPECIAL STUDIES

For the remainder of the discussion, the assumption was that the evasive burn would be performed at ejection plus 150 seconds, would be 6 seconds in duration, and would be performed at an attitude pitched up 50° from the ejection attitude (unless otherwise stated).

Spacecraft Look Gimbal Angles

Subsequent to completion of the RCS evasive burn, the crew was oriented to an attitude suitable for observing the S-IVB until its first reignition. A simulation was programed which would orient the SC to enable the crew to visually monitor the S-IVB through the hatch window. The simulation then printed a gimbal angle time history which retained the S-IVB in the center of the window indefinitely. These data are presented in figure 19 (pitch, yaw, and roll gimbal angles versus time). This attitude profile was not an attitude time line for the crew to fly; rather, the information allowed the crew to orient to an attitude at a given time in order to see the booster. After visual contact had been made the crew could then track by manual procedures.

The results of the simulation, which were employed in constructing figure 19, are contained in table IV. Evasive maneuver sequence used in the simulation is given in table III and its origin will be discussed under a section concerned with a 70 percent efficient ejection system. Figures 20(a) through 20(f) show what the crew was expected to see out the center hatch window at 5-minute intervals begining with evasive burn cutoff. Land masses on the earth are indentified. The view was restricted by the window geometry as indicated by the window outline on the figure. A small x denotes the spacecraft +X axis.

Additional Evasive Maneuver

In the following discussion the crew was assumed to have performed the recommended evasive sequence and was in an attitude to observe the S-IVB. For this situation an analysis was conducted to determine the crew reaction if the S-IVB were approaching too closely and an additional evasive burn was apparently needed. To simplify the problem the SC was assumed to be located along the nominal evasive maneuver trajectory and oriented to the attitudes given in figure 19 for a given time. Figure 21 indicates that an additional 3 seconds of RCS burn with the four SM RCS -X thrusters would have produced a greater separation distance for all cases considered. Again, the SC would

probably not reflect the attitudes given in figure 19 even if it were moving in the nominal trajectory. Therefore, if any additional RCS evasive burn were needed, the crew would be required to orient the SC to an attitude as defined in figure 19 which corresponds to time.

70 Percent Efficient Spring Ejection System

Tests on the spring ejection system indicated that only 70 percent of the previously planned ejection efficiency could be guaranteed for mission design purposes. Simulations of the previously proposed ejection and evasive maneuver sequence with the newly defined ejection characteristics showed that recontact problems existed for Apollo 9. The first requirement for a new evasive maneuver was that the LM footpads must be at least 11 feet beyond the closest point of the S-IVB [spacecraft LM adapter (SLA) top ring] at the time of orientation initiation. Also, the orientation procedure should have been initiated by ejection plus 25 seconds to insure that the crew was at the proper attitude at ejection plus 150 seconds.

The ΔV lost in the new system was approximately that obtained by burning the four SM RCS -X thrusters for 3 seconds. This burn was implemented into the sequence to insure the desired separation distance at ejection plus 25 seconds. The burn was initiated subsequent to ejection to avoid wasted fuel because of burning before separation. The burn was initiated at ejection plus 5 seconds (fig. 22) and was found to satisfy all constraints.

The relative motion for inplane and out-of-plane separation distances is presented in figures 23(a) and 23 (b), respectively. Total separation distance versus time from ejection is also presented in figure 23. No recontact problems were found in these cases. As pointed out in figure 21, the time of the evasive burn was delayed for an additional 30 seconds to relieve the crew in orienting to the burn attitude. This change is also reflected in figures 23 and 24 with the generation of no recontact problems. Figure 22 shows the recommended ejection and evasive maneuver time line.

Early Staging

Problems were defined which might necessitate the premature shutdown of the S-II stage and the continued ascent to orbit with the S-IVB. Therefore, the recommended evasive sequence was simulated to encompass the range of vents and weights which might be experienced for early stagings at various times in the launch-to-orbit phase. Table V defines the cases considered. These cases

range from the nominal case (heavy S-IVB) in which the nominally expected vent (12.5 lb) is used to the case of an empty booster at orbit insertion. The vent data on the empty S-IVB case were taken from Apollo 8 data in which a TLI burn was executed while the middle-weight case employed a 12-pound vent. The vents on the light-and middle-weight cases were high for the fuel quantity remaining and represented an upper boundary for recontact.

The simulated sequence was programed for the recommended sequence as well as for a propellant impact approximation which accounts for the free fuel mass in the actual case (fig. 25). Figure 26 represents the relative motion encountered for each case. The close-in separation distances were not greatly affected within the first few hundred feet and no recontact problems were generated. Therefore, early stagings to the S-IVB during the ascent-to-orbit phase of the mission required no change in the recommended evasive maneuver sequence of events.

S-IVB Relight Contingencies

As pointed out in the maneuver constraints, the recommended maneuver procedure would be valid for contingencies such as an S-IVB reignition failute. The simulated cases indicated that no recontact occurred for a reignition failure in which the SPS-1 was nominally performed. Figures 27 through 29 show the relative motion of the CSM/LM with respect to the S-IVB for the following cases, respectively.

1. SPS-1 and S-IVB contingency burn

2. No SPS-1 with S-IVB contingency burn

3. No SPS-1, no contingency burn with S-IVB dump

The in-plane separation distances show that recontact would not occur for a range of S-IVB vent magnitudes. However, small dispersions in the contingency burn attitude could result in near recontact for a 15-pound vent case (fig. 27). However, actual conditions show a miss distance at closest approach of over 1 mile.

Ejections for One Revolution

Ejection might have been required after the nominal ejection time for Apollo 9. An analysis of this requirement was conducted to determine the construction of revolution segments and corresponding evasive attitudes in which recontact could be avoided in each respective region. For simplicity, the revolution was divided into a minimum number of segments and is presented in figure 30. The region boundaries are defined at the top of the figure according to g.e.t. at the beginning and the end of each region. The corresponding evasive attitudes for each region are defined in table VI. Region I attitudes are defined in gimbal angles while regions II and III are defined in terms of LV and LH attitudes. Figure 31 also shows each evasive burn attitude at the time of burn initiation. Figures 31 through 33 show the resulting long-range and close-in relative motion for each region with several check cases chosen in each region. The regions as defined in conjunction with the recommended evasive attitude resulted in no recontact areas. The ejection sequence defined in table II was employed in the simulation along with the 6-second RCS burn and 15-pound vent. The close-in motion of the table II sequence so closely approximated that of the recommended sequence that reanalysis was deemed unnecessary. Certain factors which were considered in each regional definition should be pointed out. First, the S-IVB was assumed to retain its inertial attitude (T&D) throughout the simulation (no information to the contrary was available). Second, the PV magnitude was assumed to be a 15-pound worst case. Third, no S-IVB relights or SPS-1 burns were simulated because of a lack of information on how they would be rescheduled.

The problem was further simplified by assuming the following.

1. The region I attitudes could be employed throughout the complete region I area which would eliminate the majority of region III.

2. Region III could probably be eliminated, except in emergencies, because it occurs in darkness where ejection is unlikely.

This simplification left only regions I and II.

THE LAST EJECTION OPPORTUNITY

The question arose during the analysis as to how long the ejection could be delayed and still insure a separation distance of 500 feet between the CSM/LM and the S-IVB at nominal S-IVB reignition. Figure 32(b)

indicates that if ejection were delayed until as late as $4^h32^m00^s$ g.e.t., the separation distance would exceed 500 feet and place the SC in a favorable position for the S-IVB burn. However, to avoid recontact, the evasive attitudes defined for region II were to be employed.

CONCLUSIONS AND RECOMMENDATIONS

The evasive maneuver outlined in figure 22 avoided recontact between the CSM/LM and the S-IVB, and the separation distances were very acceptable to the crew of Apollo 9. This same procedure could also be applied to other earth orbital missions which might result from contingencies encountered on Apollo 11 (Mission G) and subsequent missions. The only changes from the Apollo 9 procedure might be alterations in the maneuver angle subsequent to ejection and possible changes in the RCS burn time. However, it is felt that the basic evasive sequence is recommendable for earth orbital missions.

TABLE I.- MANEUVER CONSTRAINTS

1. Minimal RCS burn time

2. Minimization of maneuvering required after separation

3. Maneuver suitable for any lift-off time or date (transposition and docking attitude)

4. Distance after separation $\geq$ 100 ft

5. Separation distance of 500 ft or more at S-IVB ignition

6. Maximization of separation distances during 20- to 35-min time period after separation

7. Not in a lateral position at ignition for any possible separation time; must be at least ahead or behind a 90° condition with origin 100 ft ahead and behind S-IVB c.g.

8. Minimization of time in a lateral position relative to S-IVB when out of sight of ground stations

9. Long-term recontact in case of no S-IVB second ignition; no problem with SPS-1 and S-IVB third ignition

10. SM RCS -X thrusters (if used) fired only for 7 sec because of LM impingement

11. S-IVB to local horizontal at HAW

12. Some mandatory S-IVB data requirements at separation

12a. Separation over CRO or daylight or HAW

$\Delta t \approx$ 43 min 34 min 20 min, respectively

12b. To separate at daylight: $\approx 4^h 11^m 00^s$ g.e.t.; may need ARIA for voice and telemetry

12c. To have ground contact: $\left\{\begin{array}{l}\text{separate at} \approx 3^h 59^m 17^s \text{ g.e.t. over CRO} \\ \text{or separate at} \approx 4^h 24^m 14^s \text{ g.e.t. over HAW}\end{array}\right.$

12d. Nominal separation at sunrise at $\approx 4^h 09^m$ g.e.t.

TABLE II.- RECOMMENDED EVASIVE MANEUVER TIME LINE

Time, min:sec	Event
00:00	CSM/LM ejection
00:00	Beginning of orientation to evasive maneuver attitude
02:30	RCS -X ignition
02:36	RCS -X off

TABLE III.- APOLLO 9 EVASIVE MANEUVER TIME LINE

Time min:sec	Event
0:00	CSM/LM separation from the S-IVB (LM ejection)
0:05	Four-jet -X SM RCS ignition (first evasive burn)
0:08	Four-jet -X SM RCS cutoff
3:00	Four-jet -X SM RCS ignition (second evasive burn with CSM/LM pitched down 50° about Y-axis)
3:06	Four-jet -X SM RCS cutoff

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TABLE IV.- SPACECRAFT GIMBAL ANGLES FOR MAINTAINING VISUAL OBSERVATION OF THE S-IVB THROUGH THE CM-104 HATCH WINDOW (SPACECRAFT PITCHED DOWN 50 DEGREES ABOUT THE Y-AXIS AT INITIATION OF 6-SECOND RCS EVASIVE BURN)

Event	Time from lift-off hr:min:sec	Spacecraft gimbal angles		
		Roll, deg	Pitch, deg	Yaw, deg
RCS ignition	4:11:57	142.84	-46.48	-54.54
RCS cutoff	4:12:03	142.84	-46.48	-54.54
Observe S-IVB	4:12:03	-163.82	-40.13	-5.57
	4:13:03	-152.30	-36.02	-6.58
	4:14:03	-144.00	-34.69	-5.59
	4:15:03	-136.61	-34.72	-3.83
	4:16:03	-129.22	-35.79	-1.70
	4:17:03	-121.31	-37.86	0.54
	4:18:03	-112.61	-40.94	2.57
	4:19:03	-103.05	-44.93	4.03
	4:20:03	-92.89	-49.52	4.44
	4:21:03	-82.66	-54.11	3.52
	4:22:03	-72.90	-58.04	1.43
	4:23:03	-64.03	-60.83	-1.52
	4:24:03	-56.17	-62.30	-4.90
	4:25:03	-49.08	-62.56	-8.23
	4:26:03	-42.49	-61.83	-11.10
	4:27:03	-36.40	-60.42	-13.35
	4:28:03	-30.85	-58.58	-14.97
	4:29:03	-25.86	-56.58	-15.98
	4:30:03	-21.42	-54.54	-16.48
	4:31:03	-17.51	-52.62	-16.57
	4:32:03	-14.10	-50.83	-16.36
	4:33:03	-11.12	-49.18	-15.92
	4:34:03	-8.54	-47.65	-15.33
	4:35:03	-6.29	-46.21	-14.63
	4:36:03	-4.34	-44.83	-13.87
	4:37:03	-2.62	-43.45	-13.05

TABLE IV.- SPACECRAFT GIMBAL ANGLES FOR MAINTAINING VISUAL OBSERVATION OF THE S-IVB THROUGH THE CM-104 HATCH WINDOW (SPACECRAFT PITCHED DOWN 50 DEGREES ABOUT THE Y-AXIS AT INITIATION OF 6-SECOND RCS EVASIVE BURN) - Continued

Event	Time from lift-off hr:min:sec	Spacecraft gimbal angles		
		Roll, deg	Pitch, deg	Yaw, deg
Observe S-IVB	4:38:03	-1.13	-42.10	-12.21
	4:39:03	0.17	-40.72	-11.35
	4:40:03	1.30	-39.34	-10.49
	4:41:03	2.29	-37.94	-9.63
	4:42.03	3.14	-36.57	-8.82
	4:43:03	3.89	-35.23	-8.04
	4:44:03	4.56	-33.95	-7.33
	4:45:03	5.20	-32.79	-6.76
	4:46:03	5.95	-31.73	-6.43
	4:47:03	7.25	-30.77	-6.78
	4:48:03	13.57	-29.03	-12.02
	4:49:03	176.03	59.69	-2.08
	4:50:03	179.79	60.02	2.23
	4:51:03	-179.74	60.00	3.15
	4:52:03	-179.77	59.72	3.50
	4:53:03	-179.92	59.22	3.64
	4:54:03	179.89	58.50	3.68
	4:55:03	179.71	57.56	3.66
	4:56:03	179.53	56.42	3.62
	4:57:03	179.38	55.08	3.55
	4:58:03	179.25	53.57	3.47
	4:59:03	179.15	51.89	3.39
	5:00:03	179.06	50.06	3.31
	5:01:03	178.99	48.10	3.22
	5:02:03	178.94	46.00	3.14
	5:03:03	178.92	43.79	3.07
	5:04:03	178.90	41.46	2.99
	5:05:03	178.90	39.04	2.92

TABLE IV.- SPACECRAFT GIMBAL ANGLES FOR MAINTAINING VISUAL OBSERVATION OF THE S-IVB THROUGH THE CM-104 HATCH WINDOW (SPACECRAFT PITCHED DOWN 50 DEGREES ABOUT THE Y-AXIS AT INITIATION OF 6-SECOND RCS EVASIVE BURN) - Concluded

Event	Time from lift-off hr:min:sec	Spacecraft gimbal angles		
		Roll, deg	Pitch, deg	Yaw, deg
Observe S-IVB	5:06:03	178.91	36.53	2.86
	5:07:03	178.94	33.93	2.80
	5:08:03	178.97	31.26	2.74
	5:09:03	179.01	28.51	2.68
	5:10:03	179.07	25.70	2.63
	5:11:03	179.13	22.82	2.58
	5:12:03	179.19	19.89	2.53

TABLE V.- S-IVB WEIGHT AND CONTINUOUS PROPULSIVE VENT FORCE FOR EACH CASE CONSIDERED IN EARLY STAGING

Case	S-IVB weight, lb	Vent force, lb
I	33 000	3.0
II	110 000	12.0
Nominal	190 000	12.5

TABLE VI.- DEFINITION OF CSM ATTITUDE FOR EVASIVE BURNS INITIATED IN THE RESPECTIVE REGIONS

Region	Evasive burn attitude					
	Gimbal angles, deg			Local attitudes, deg		
	Outer	Inner	Middle	Pitch	Yaw	Roll
I	127.57	324.36	355.36			
II				-110	0	0
III				160	0	180

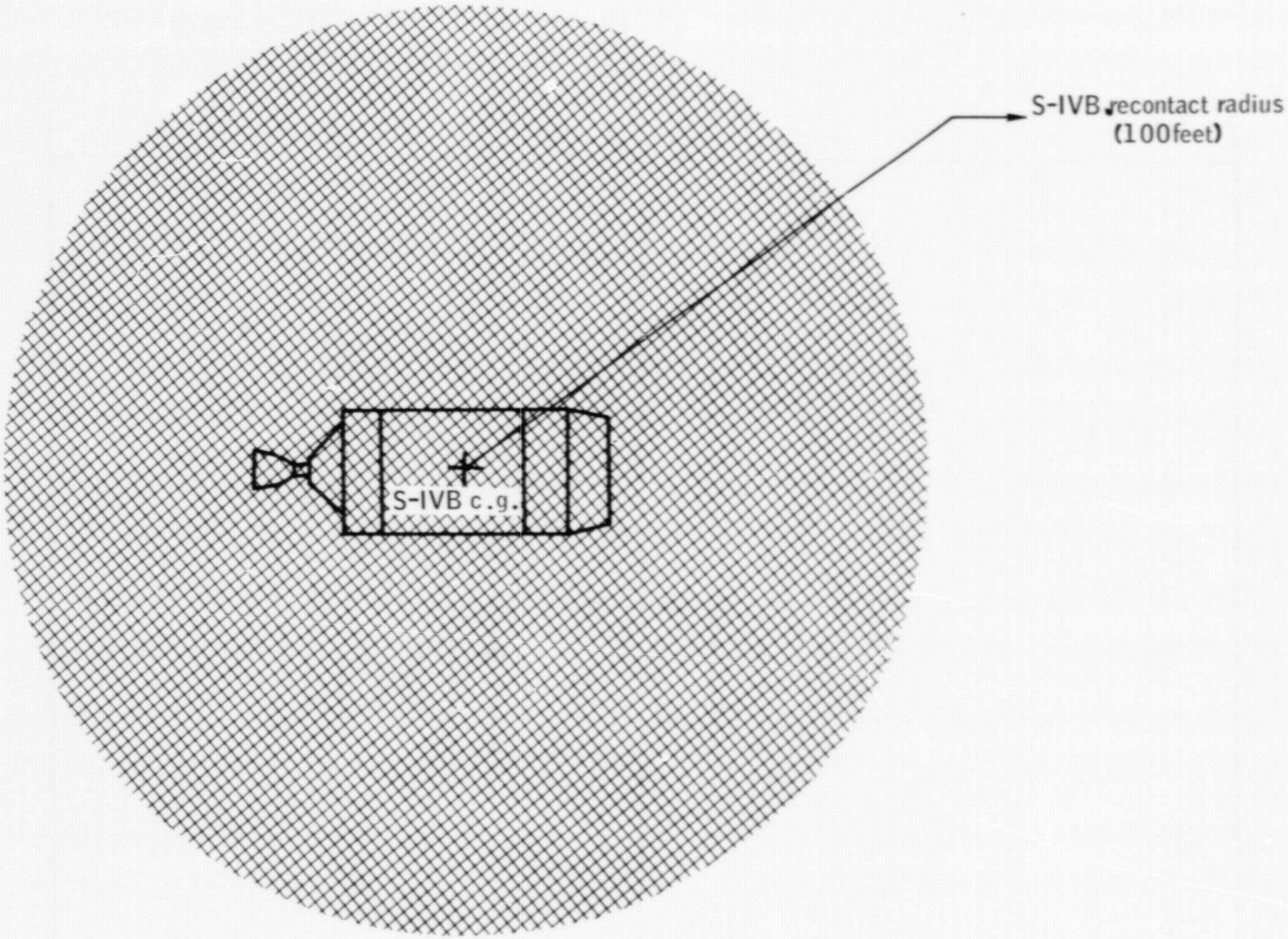


Figure 1.- S-IVB recontact area.

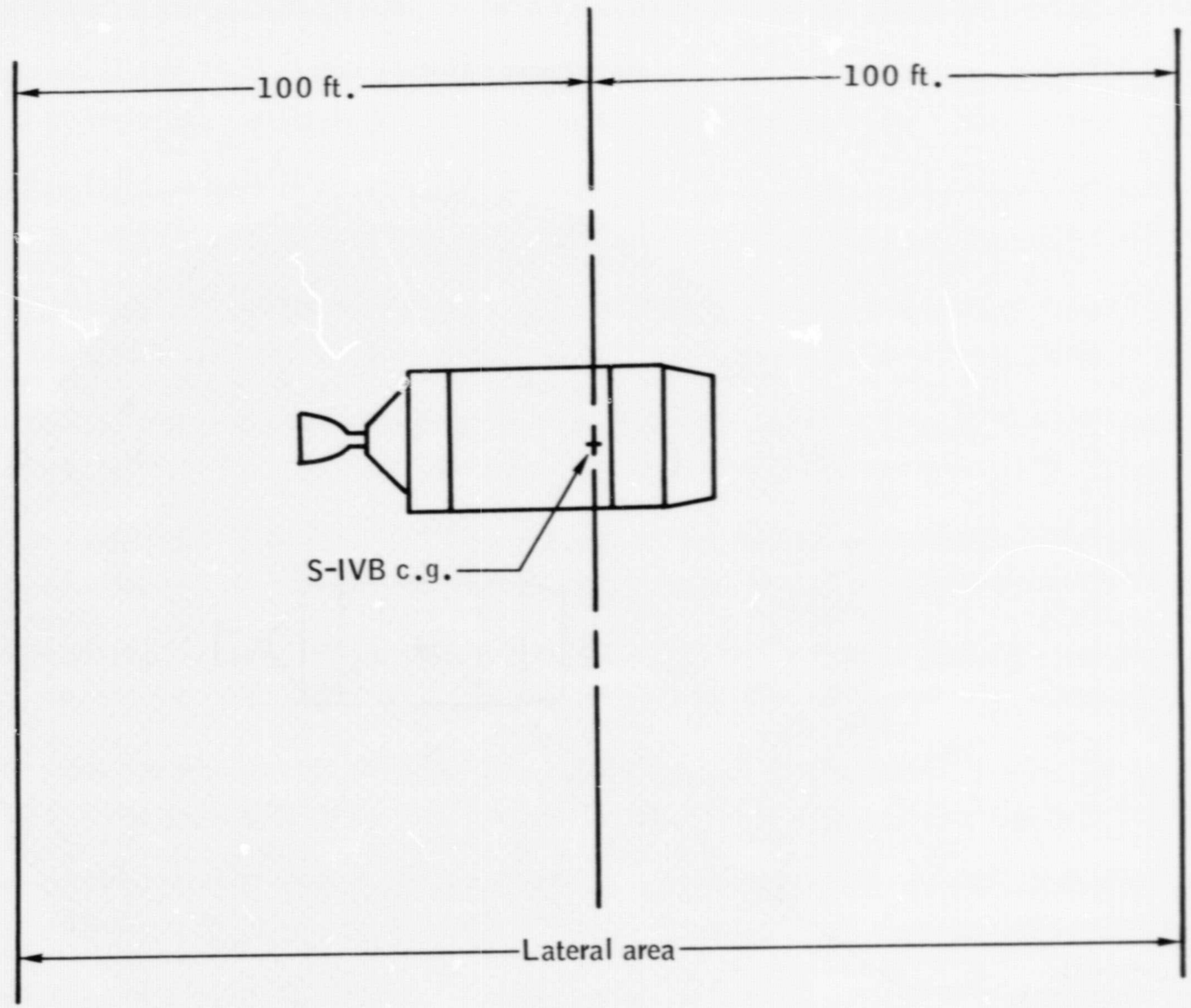


Figure 2.- S-IVB lateral area.

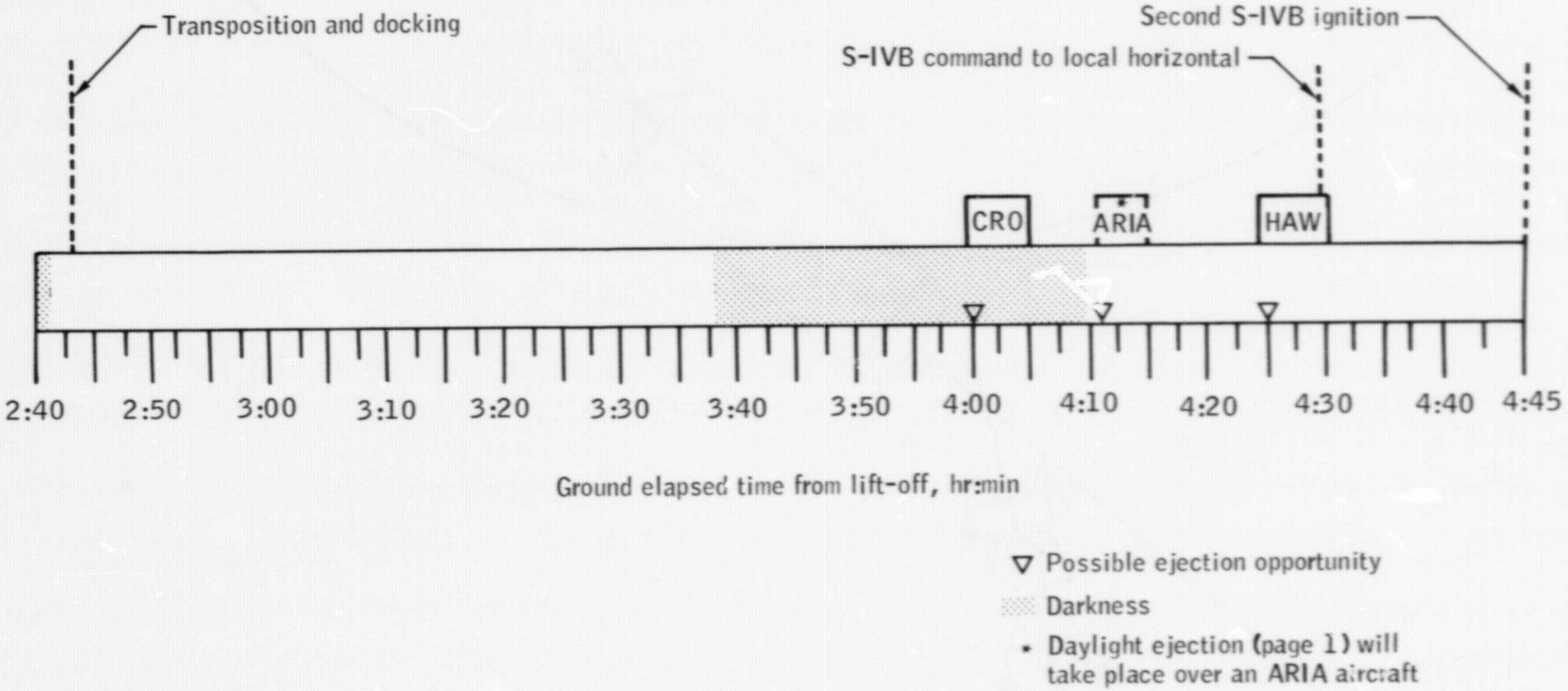


Figure 3.- Groundtrack timeline from transposition and docking to second S-IVB ignition.

θ-Evasive maneuver attitude of the CSM/LM with respect to S-IVB

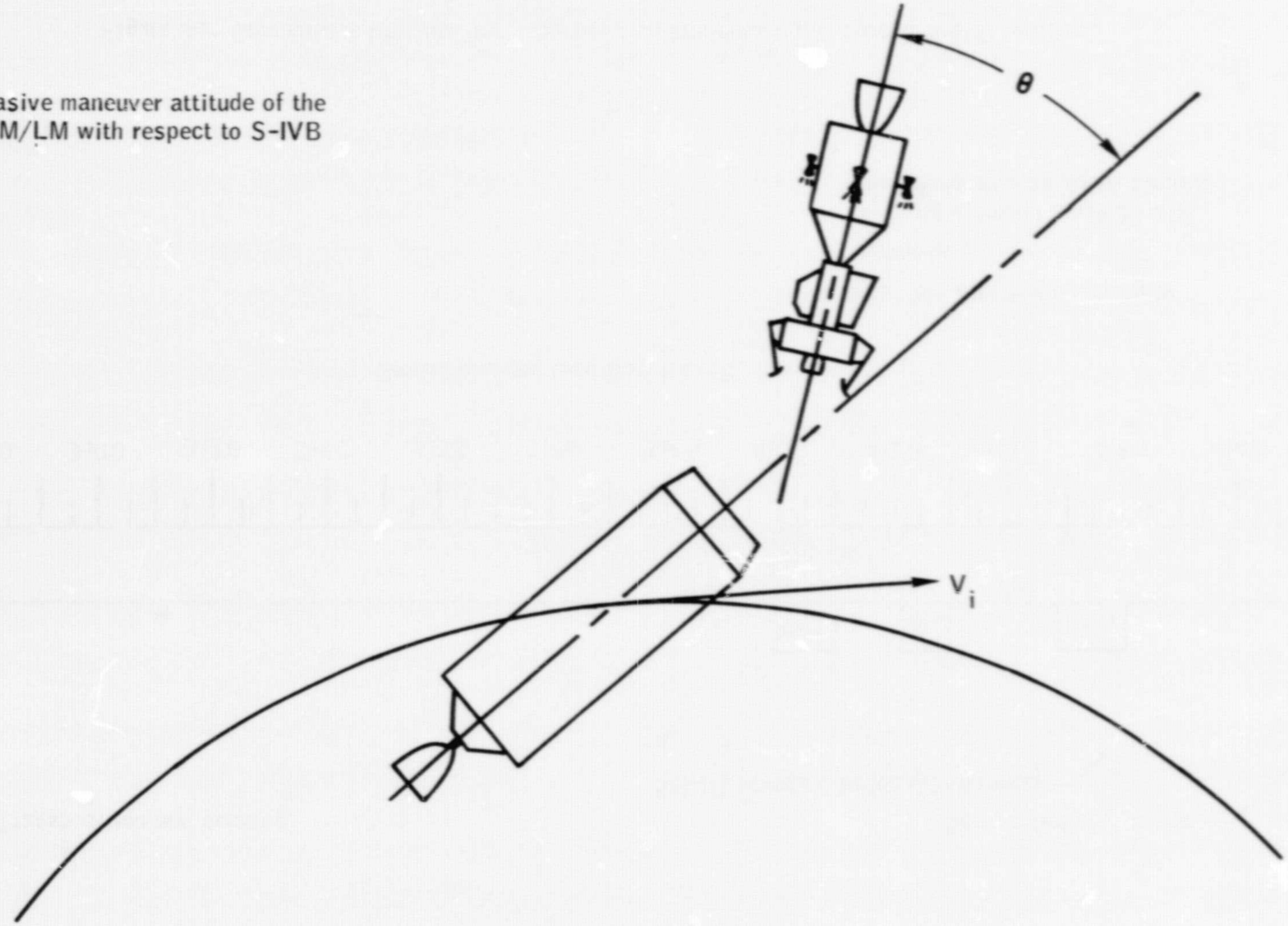


Figure 4. - Representation of the attitude maneuver required subsequent to CSM/LM ejection and prior to the evasive maneuver burn (-X)

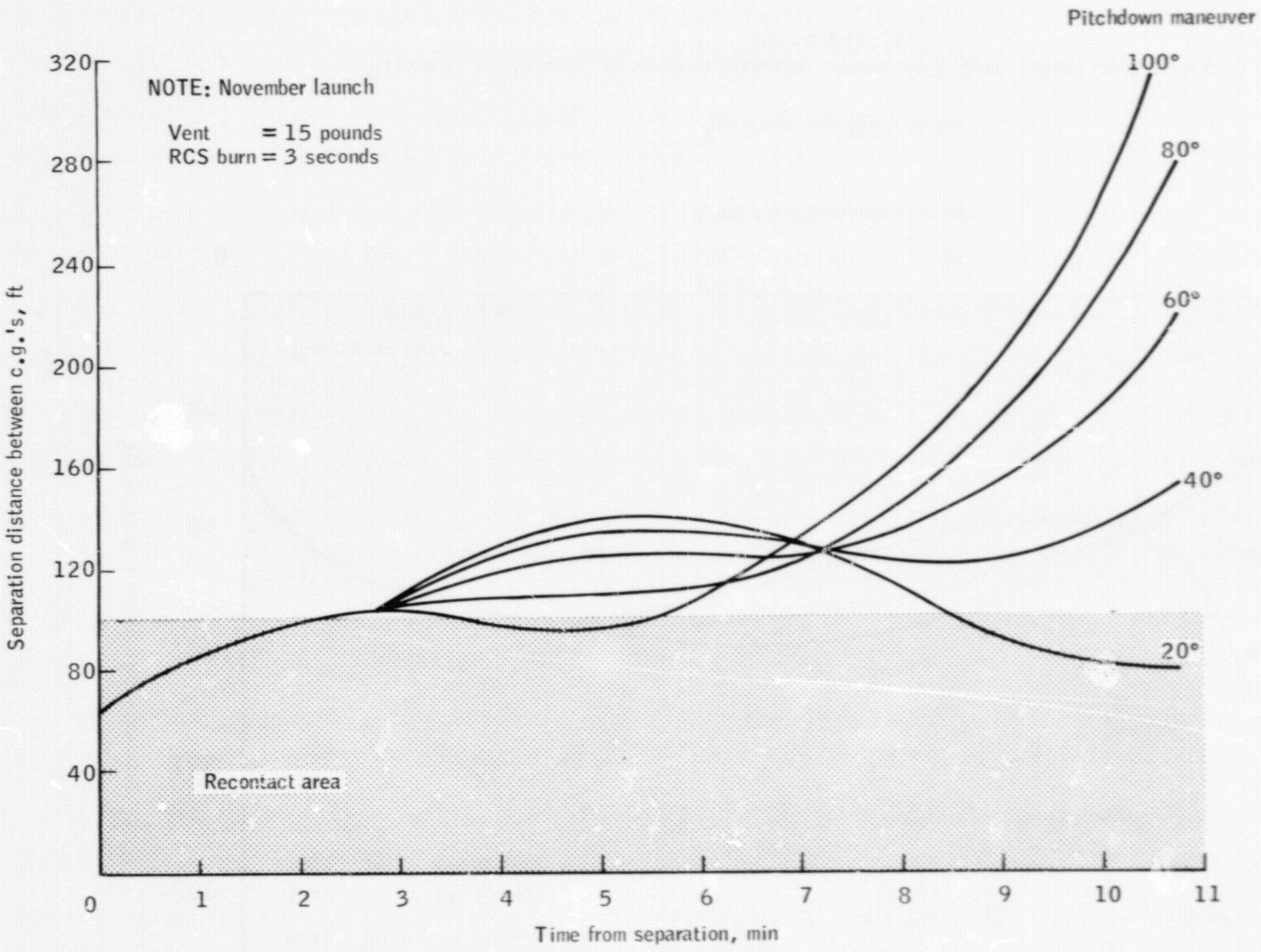
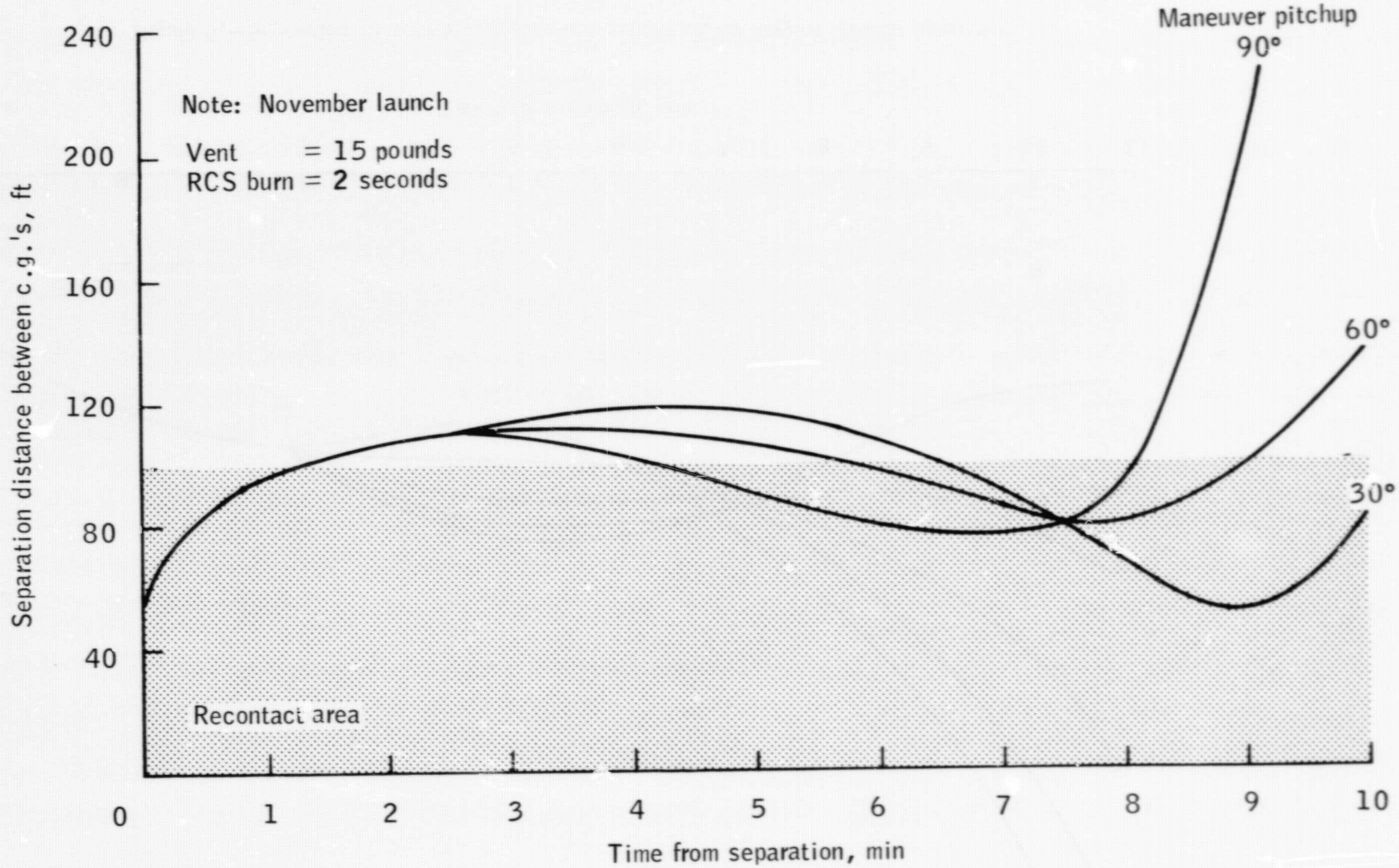
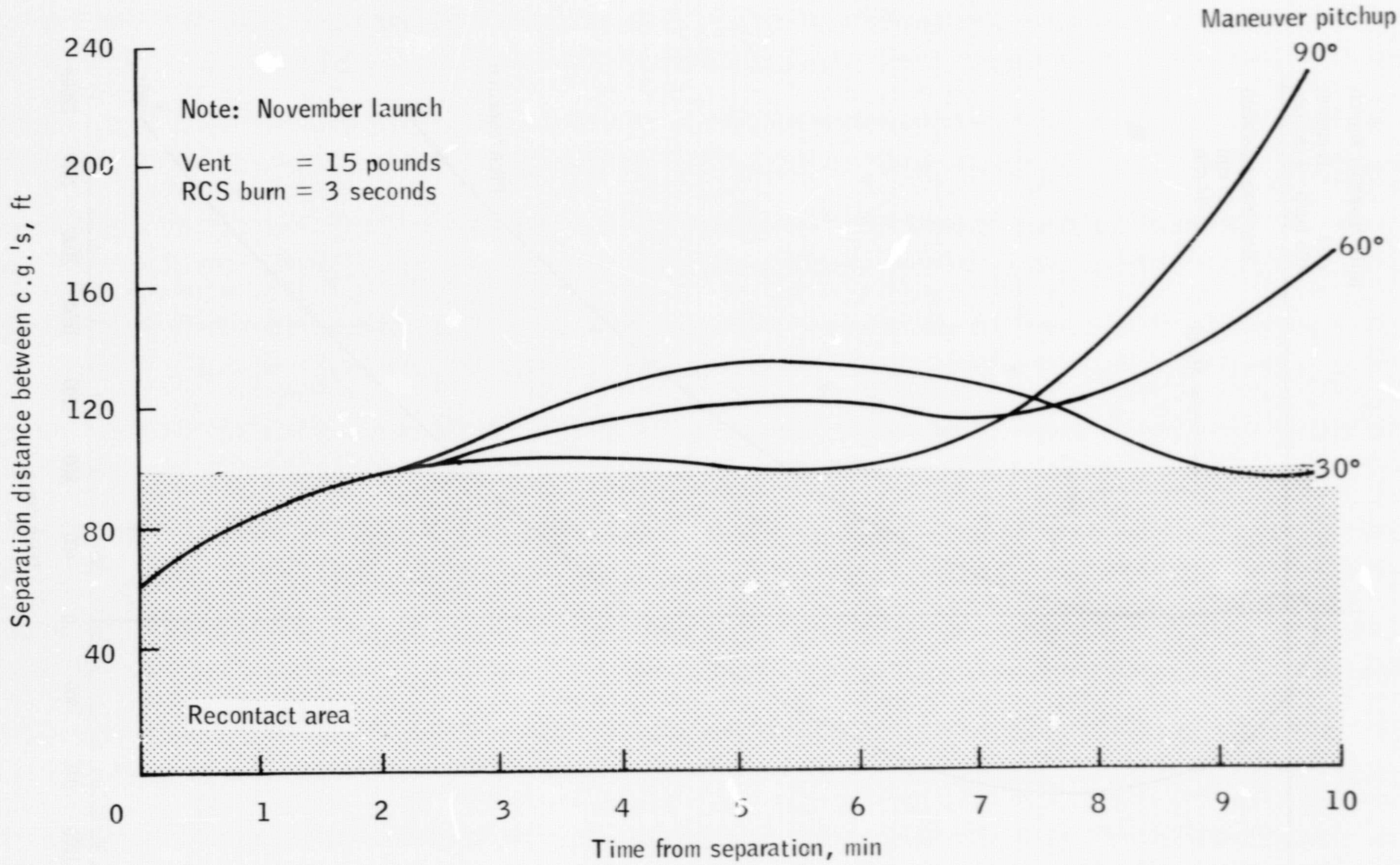


Figure 5.- Separation distance versus time from separation for varying attitude maneuvers.



(a) 2-second RCS burn.

Figure 6.- Close-in separation distance versus time from separation for varying RCS burn attitudes.



(b) 3-second RCS burn.

Figure 6.- Concluded.

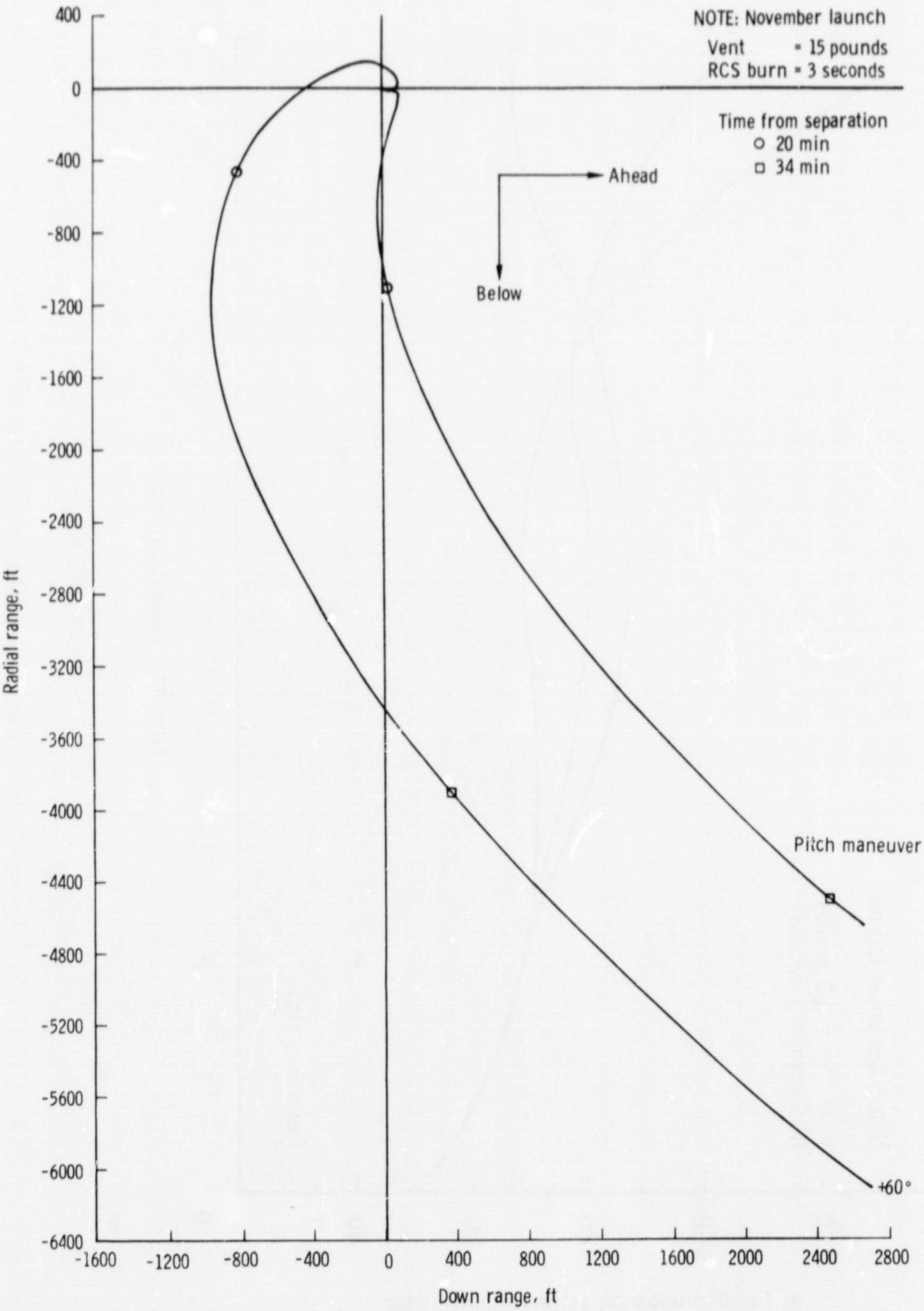


Figure 7. - CSM/LM motion relative to the S-IVB.

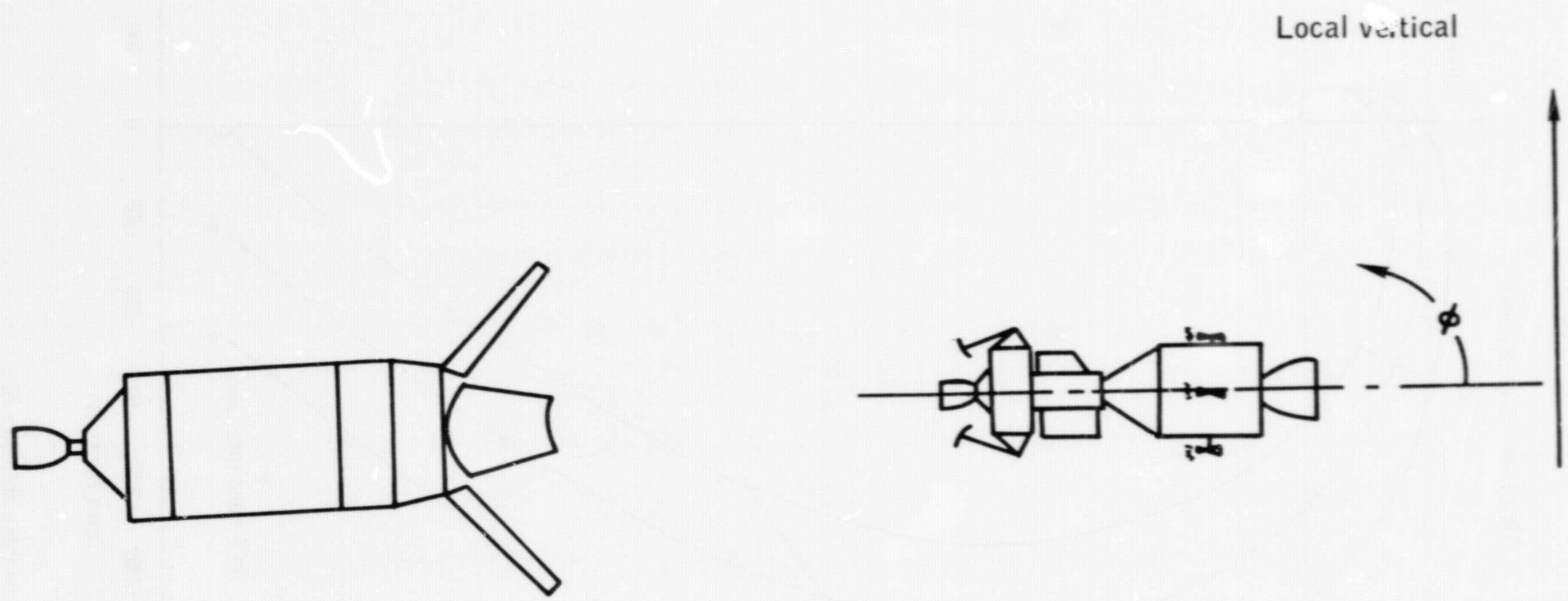
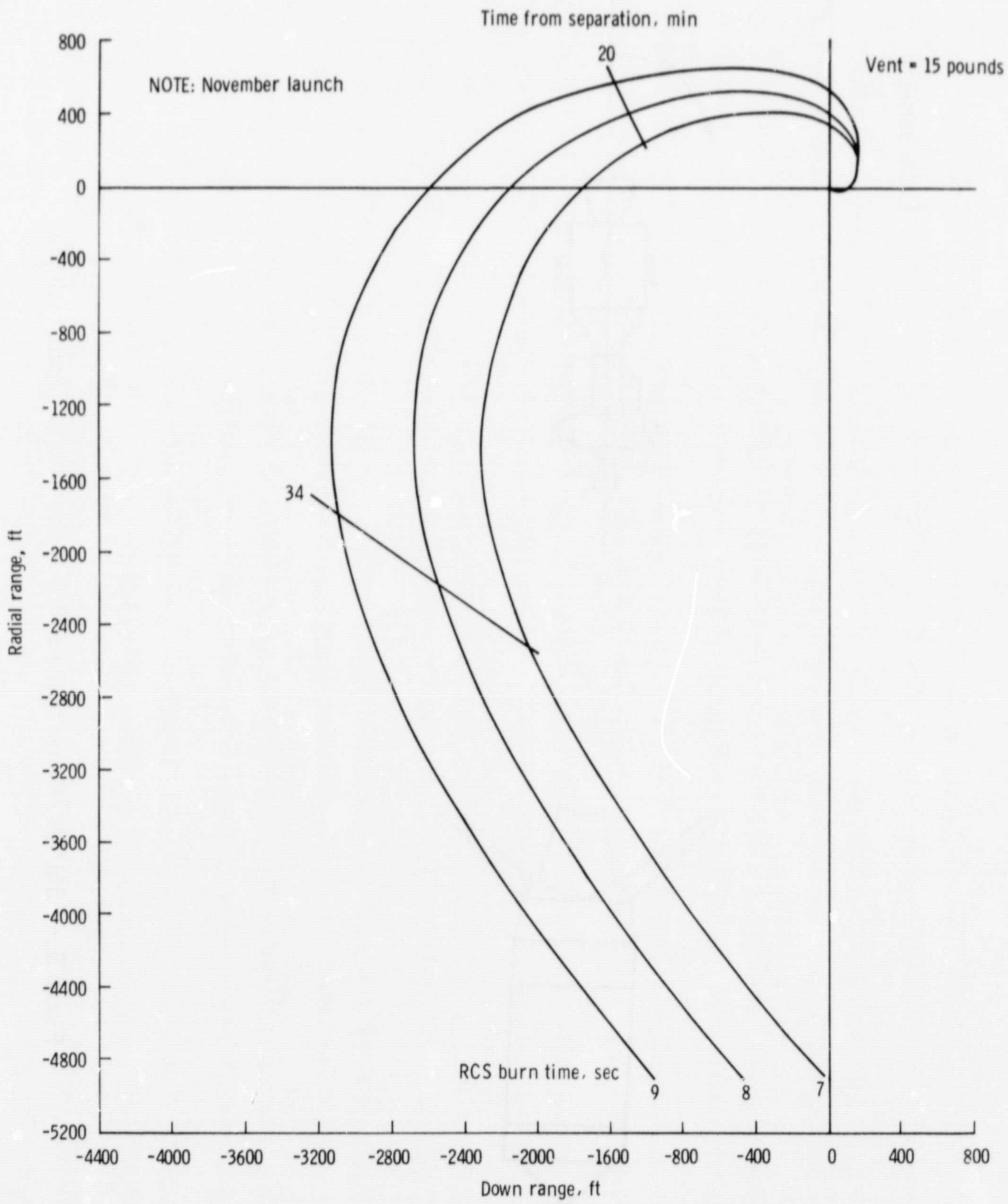
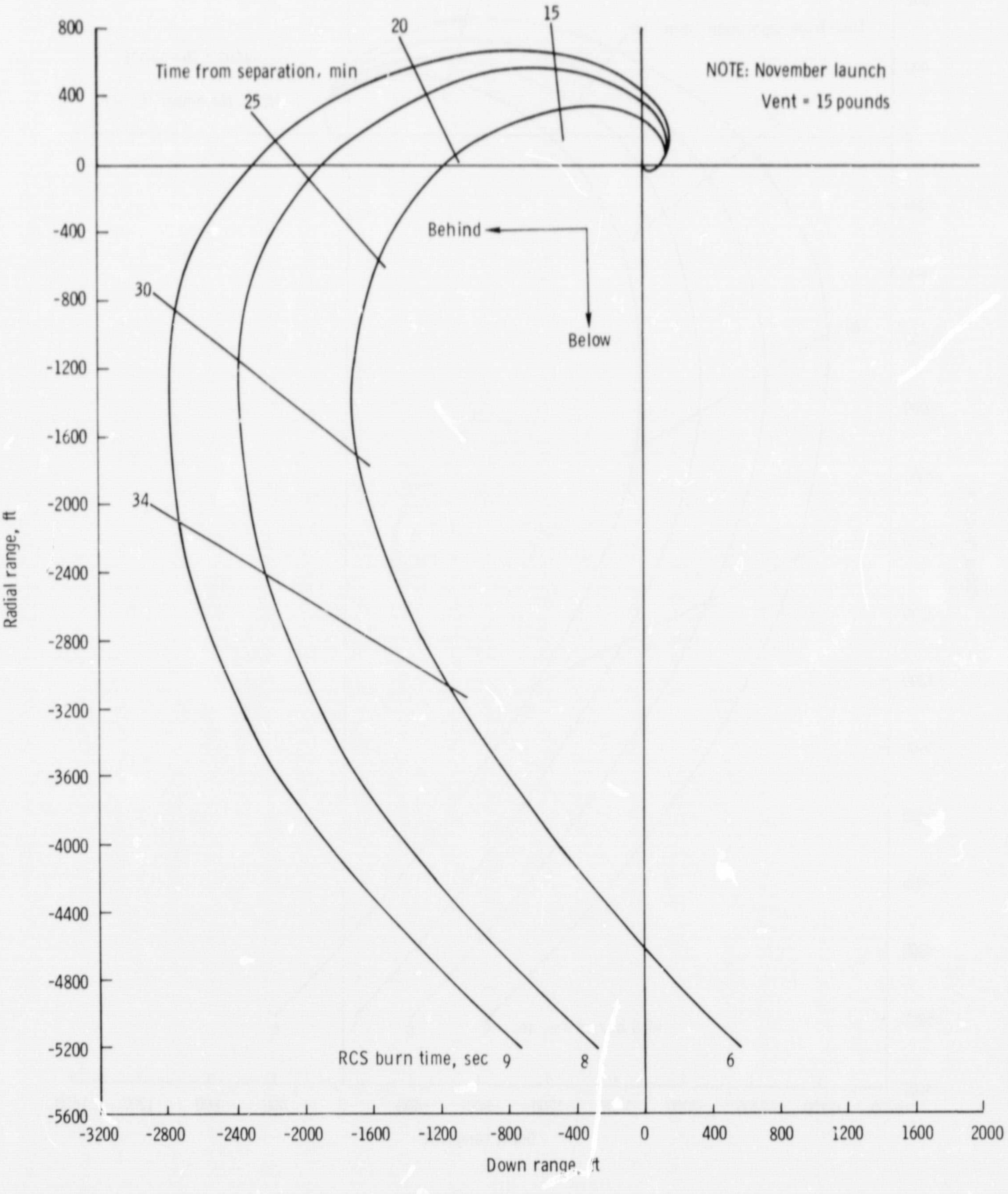


Figure 8.- CSM/LM relative to the S-IVB at maneuver orientation initiate



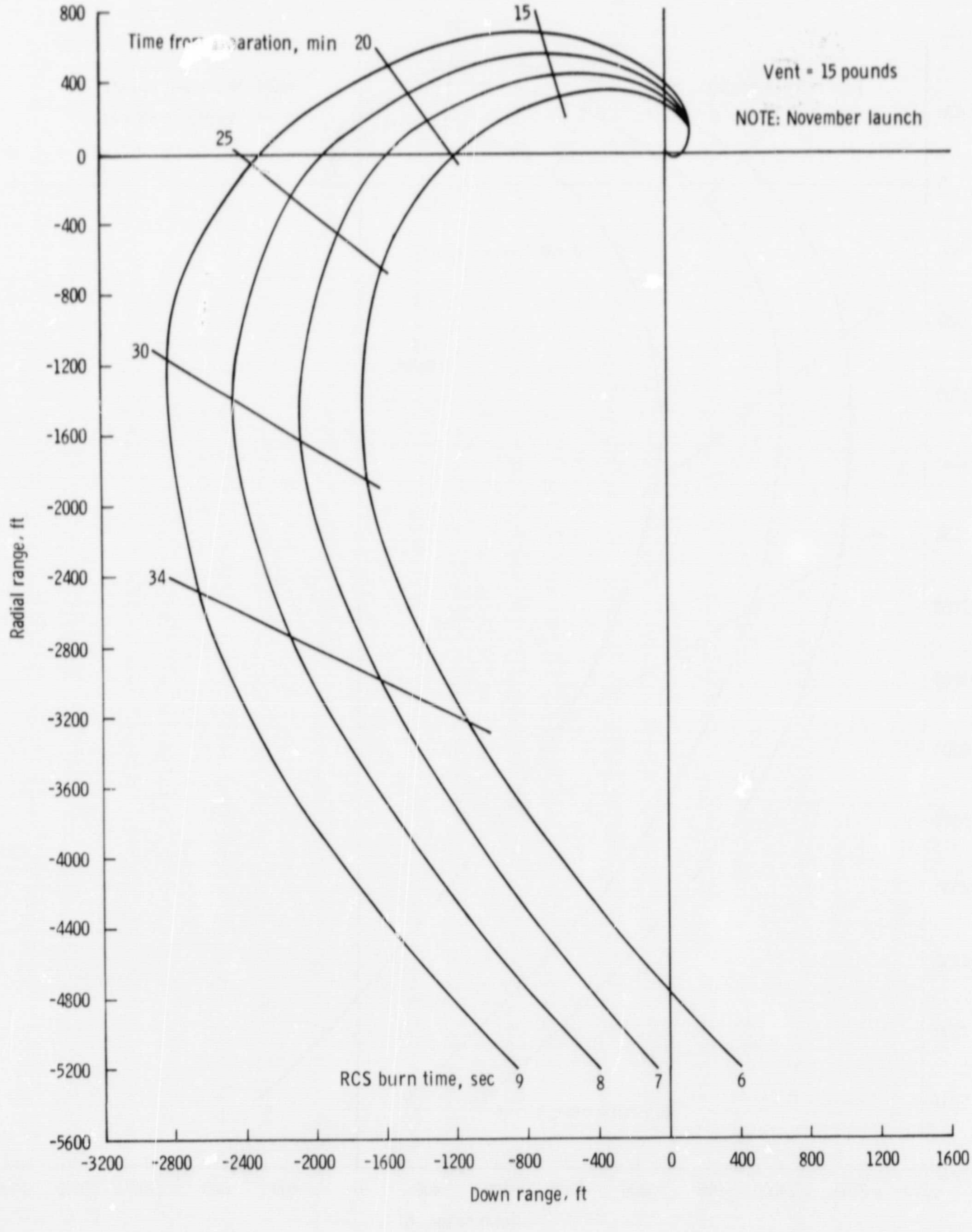
(a) Pitch attitude = 40°.

Figure 9. - CSM/LM motion relative to the S-IVB for varying RCS burn times.



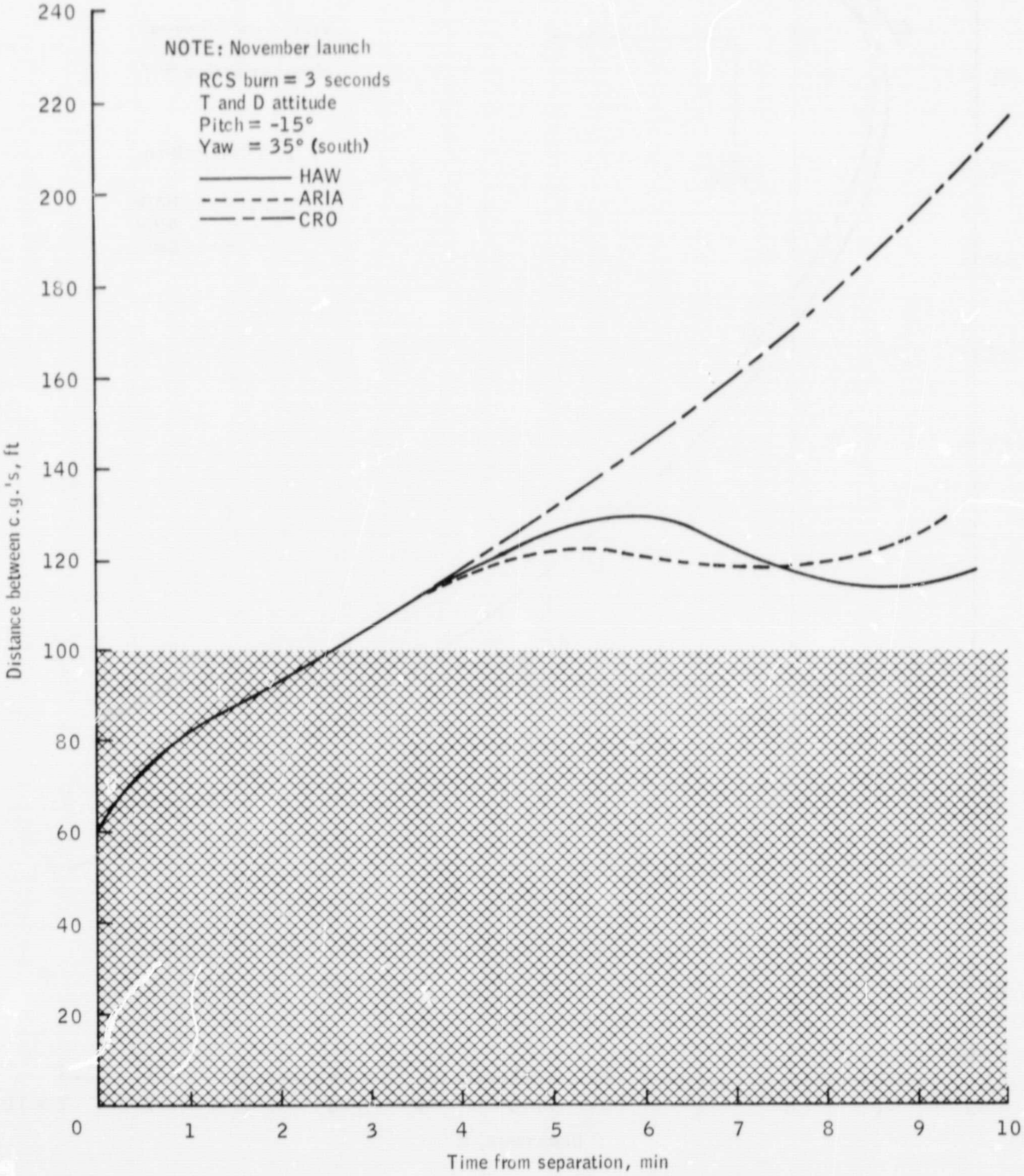
(b) Pitch attitude = 50°.

Figure 9. - Continued.



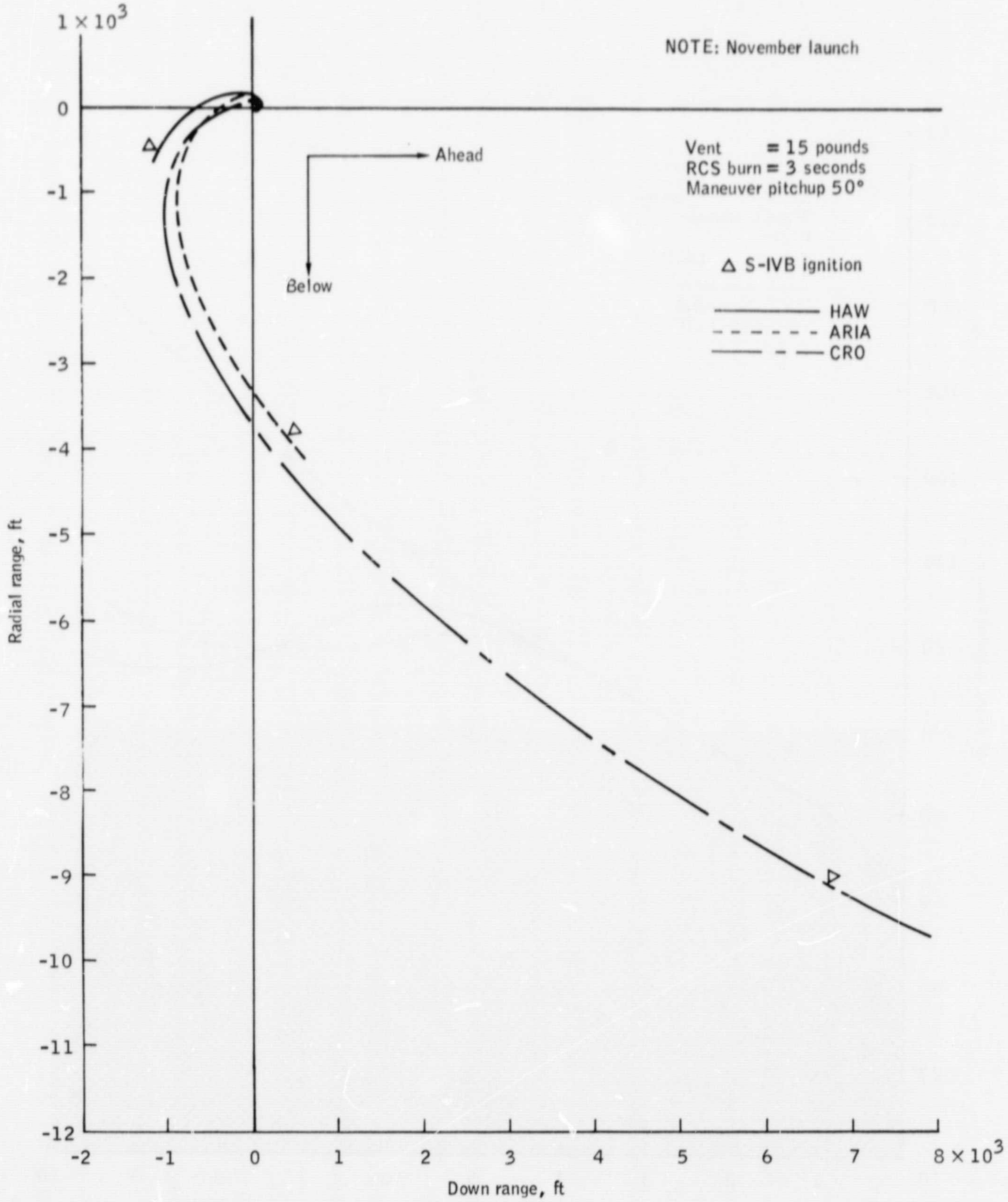
(c) Pitch attitude = 60°

Figure 9. - Concluded.



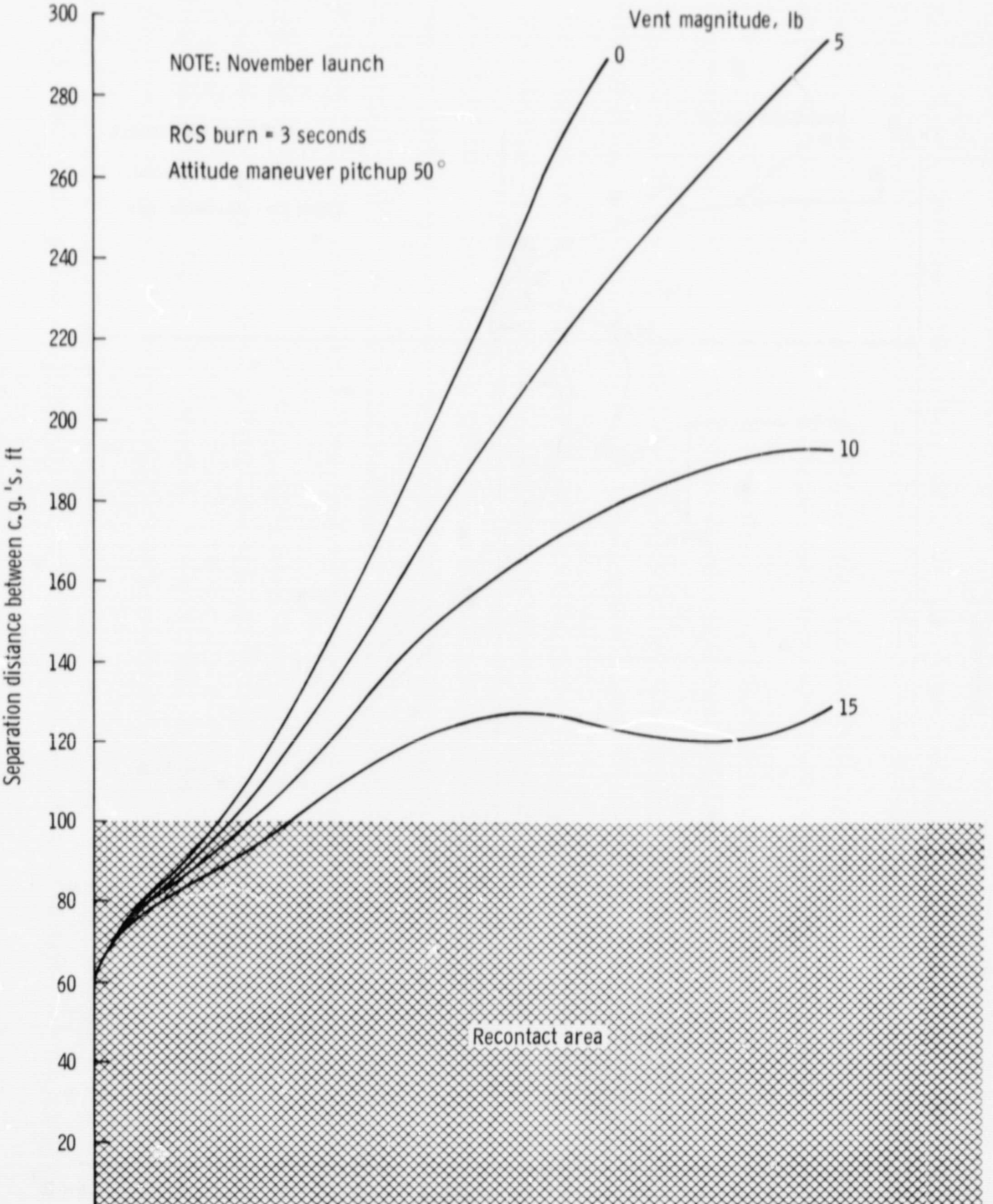
(a) Close-in motion.

Figure 10.- Separation distance between CSM/LM and S-IVB c.g.'s for close-in separation.



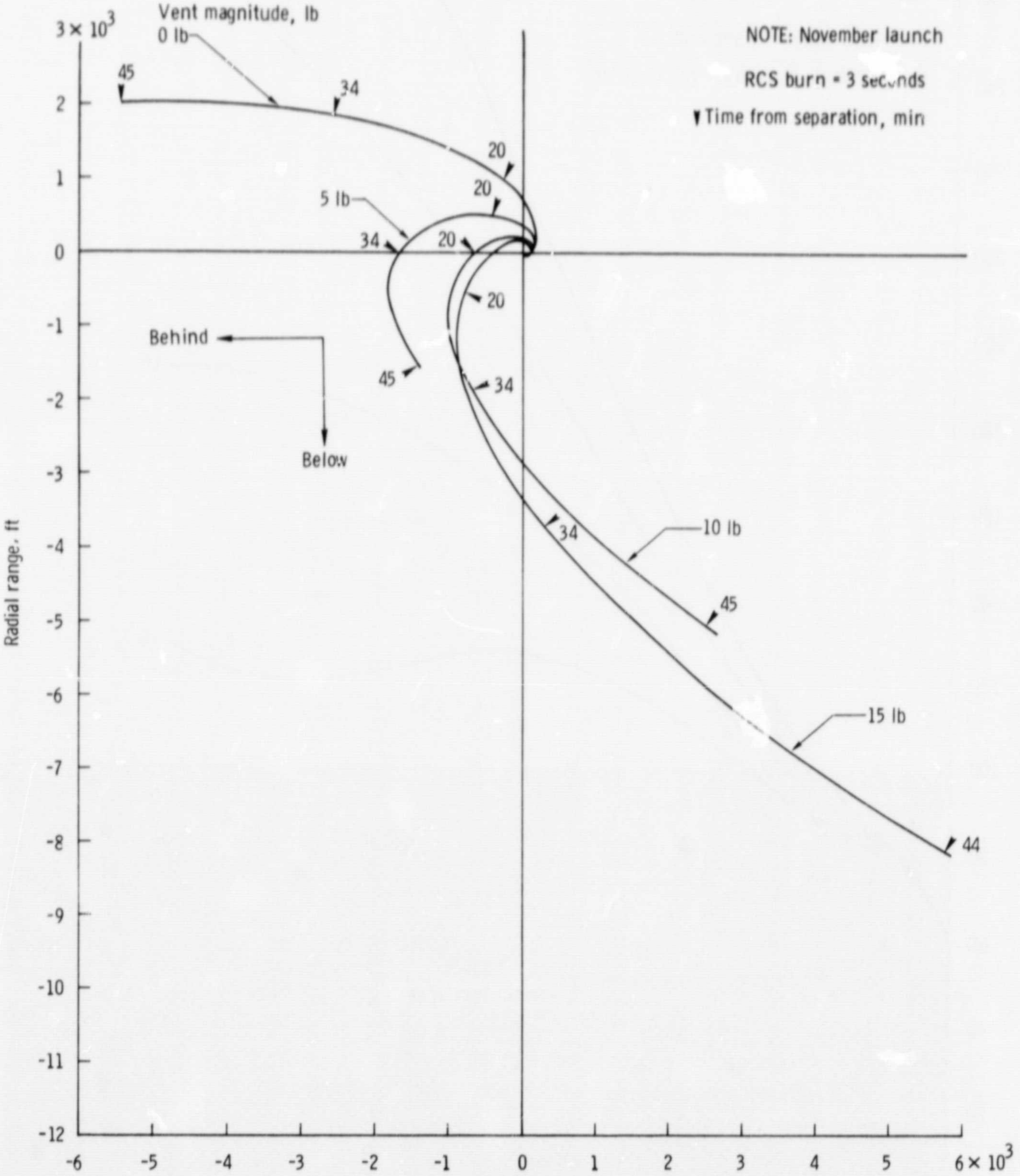
(b) Long-range motion.

Figure 10.- Concluded.



(a) Close-in motion.

Figure 11. - CSM motion relative to the S-IVB for varying vent magnitudes.



(b) Long-range motion.

Figure 11. - Concluded.

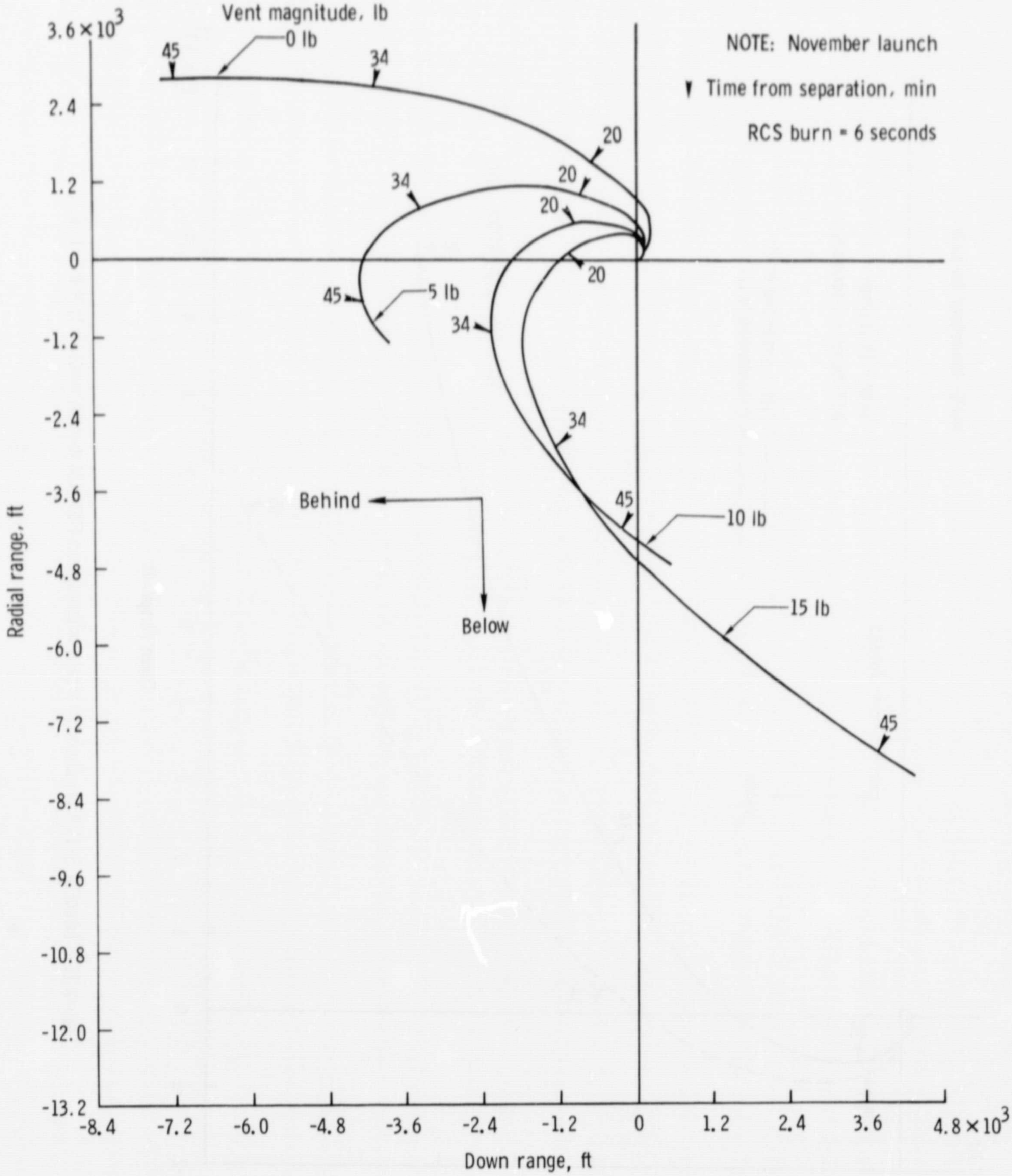


Figure 12. - CSM/LM motion relative to the S-IVB for varying vent magnitudes.

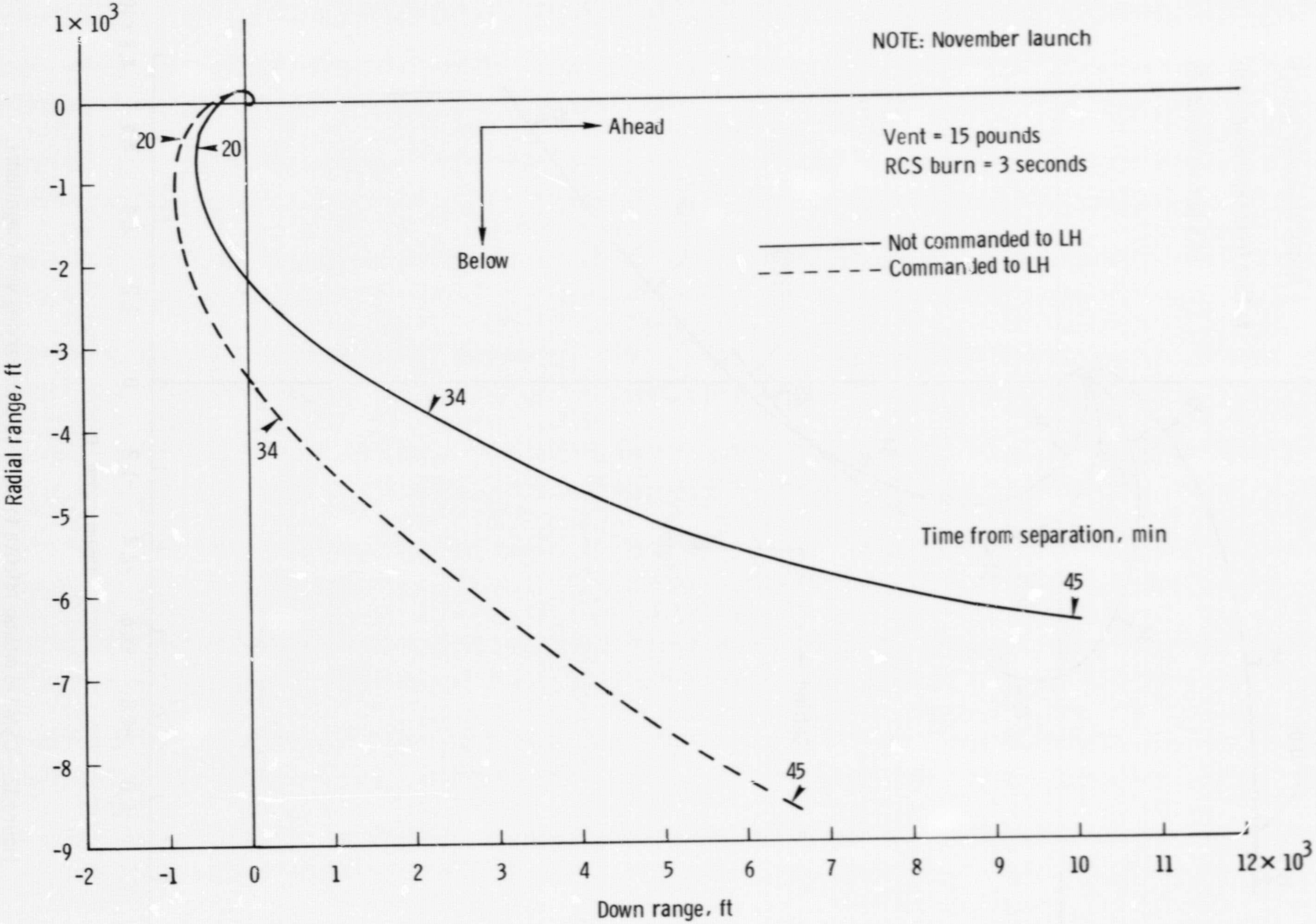


Figure 13. - Effect of S-IVB command to local horizontal on CSM/LM motion relative to the S-IVB.

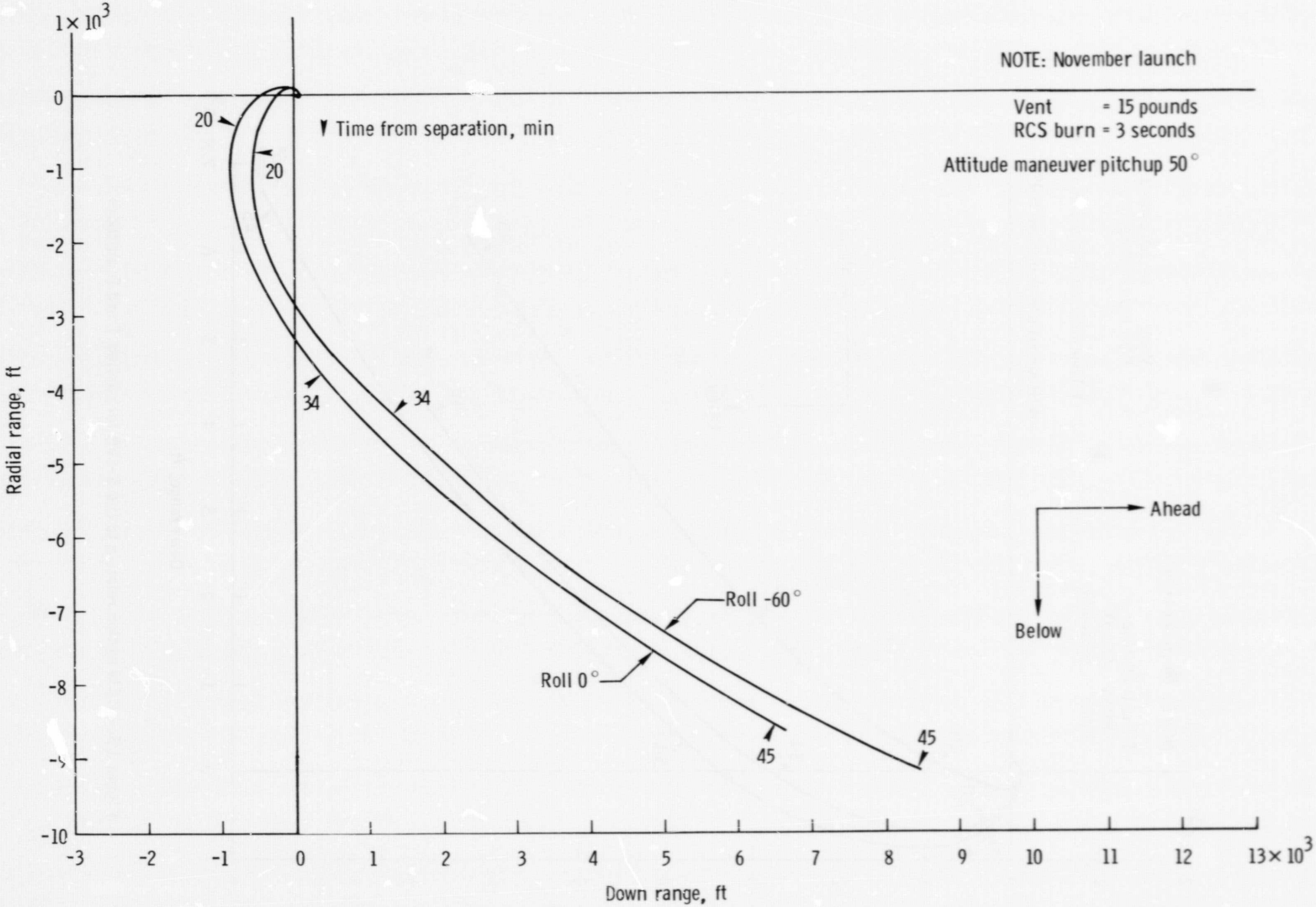


Figure 14.- Effect of roll in evasive maneuver on CSM/LM motion relative to the S-IVB.

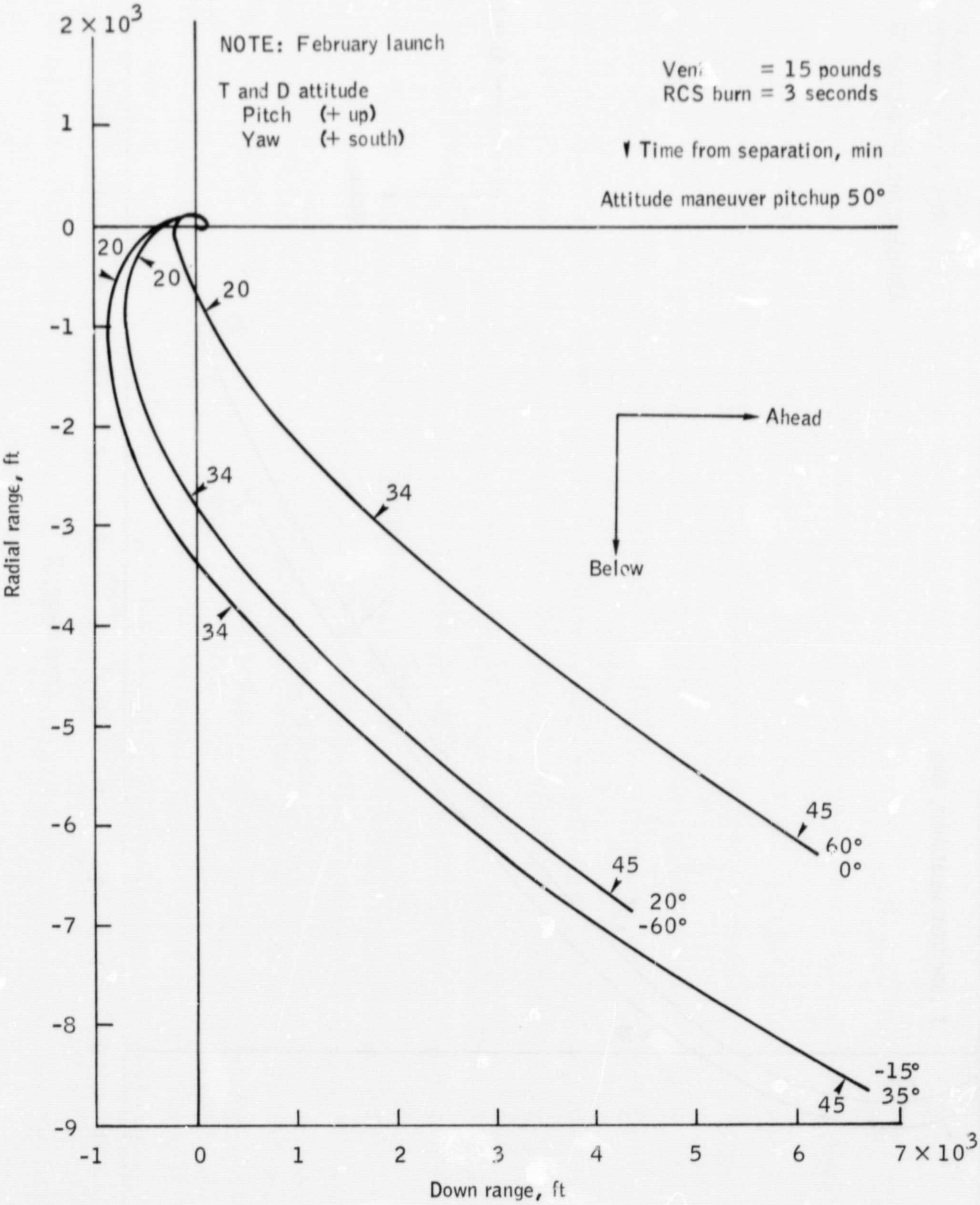
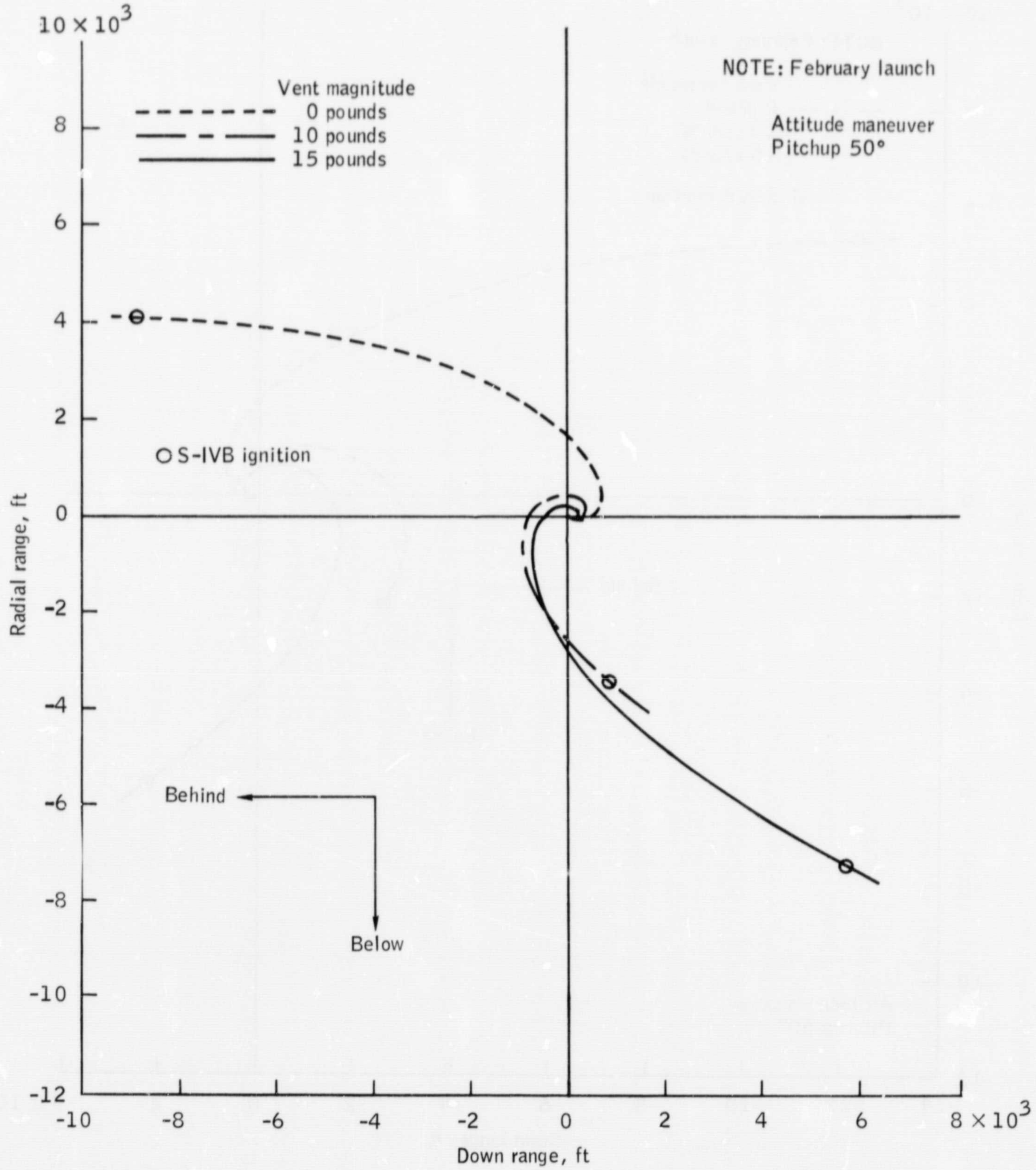
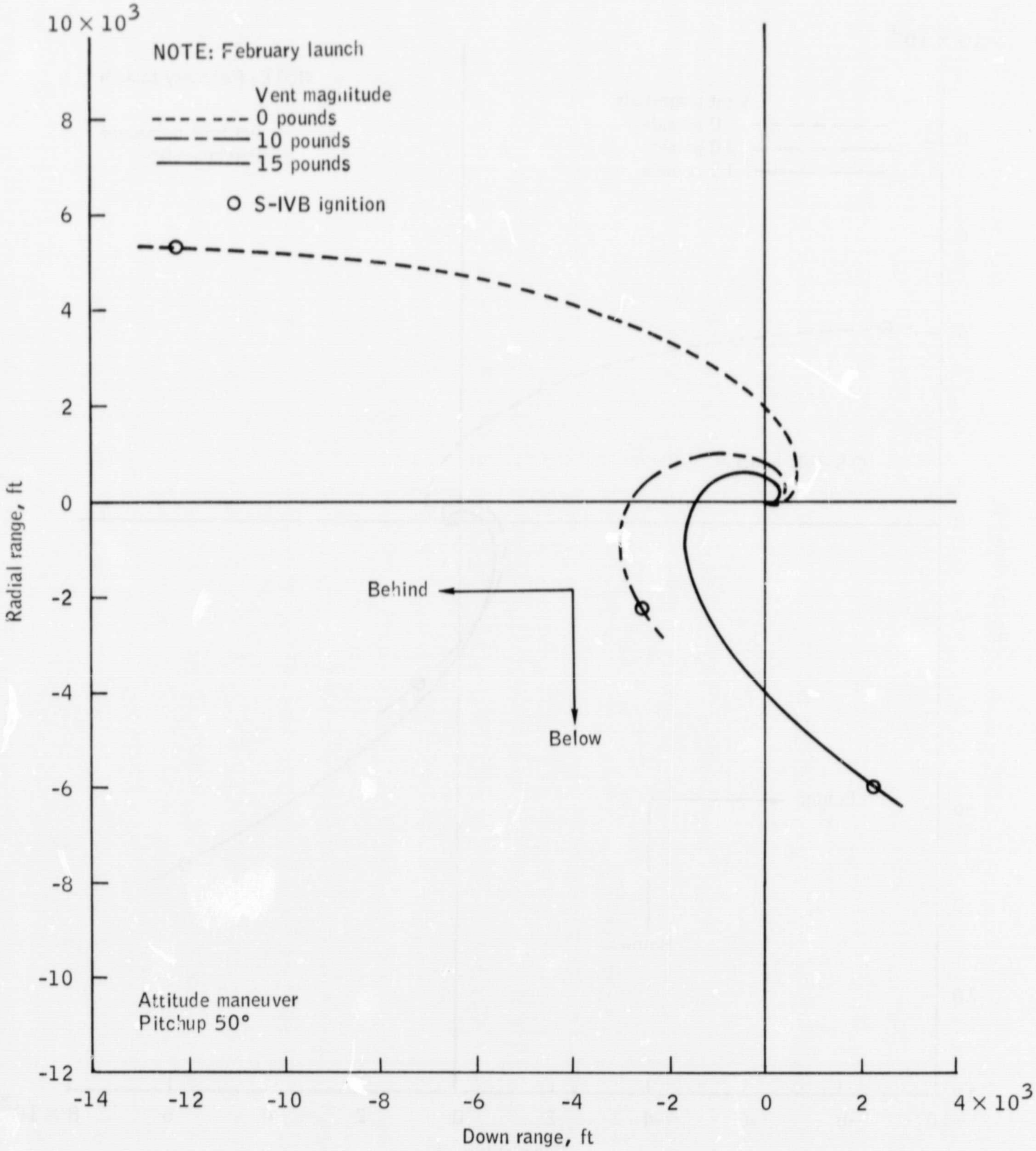


Figure 15.- CSM motion relative to the S-IVB for varying T and D attitudes.



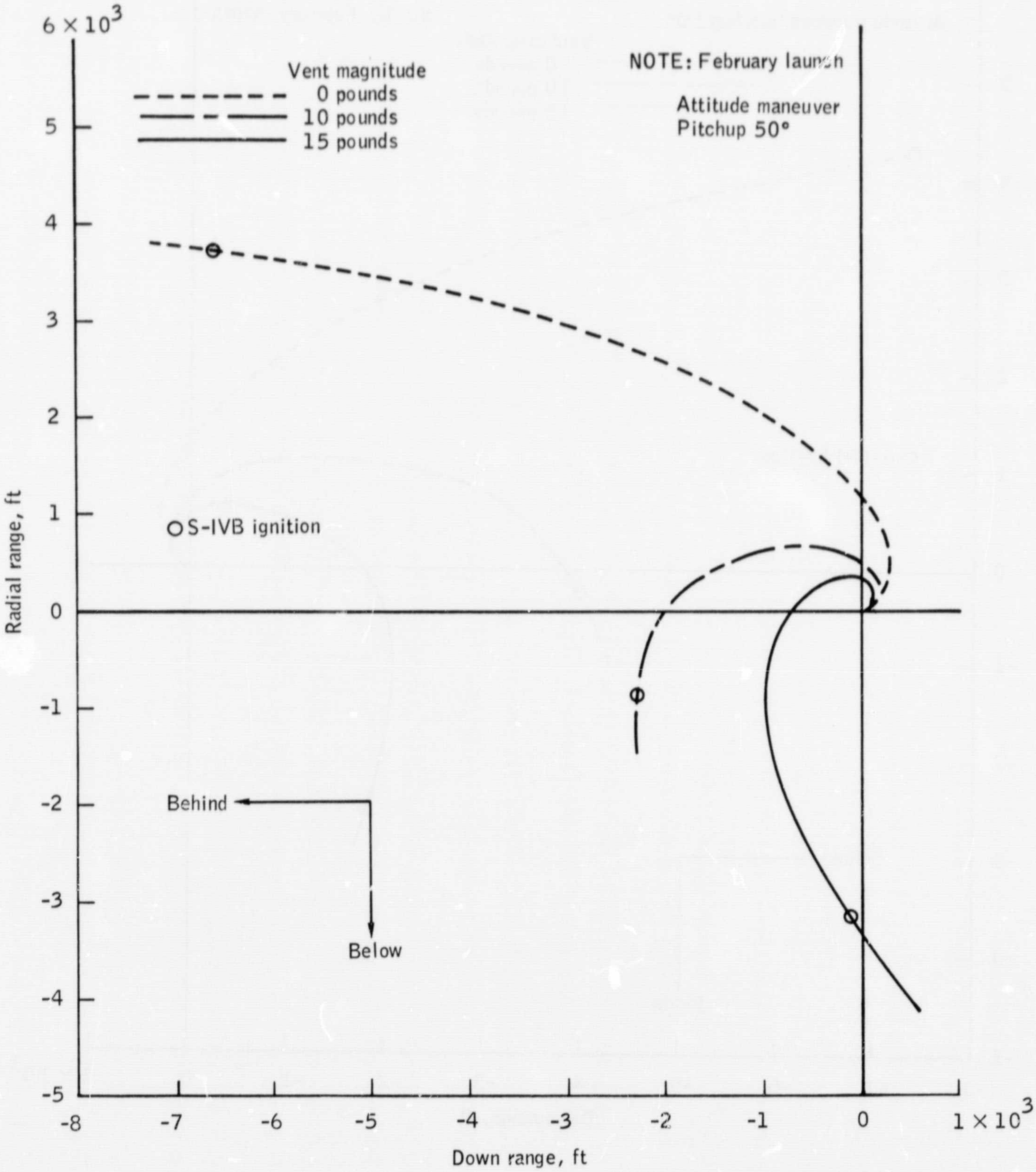
(a) 3-second RCS evasive burn.

Figure 16.- Motion of the CSM/LM relative to the S-IVB for ejection at CRO.



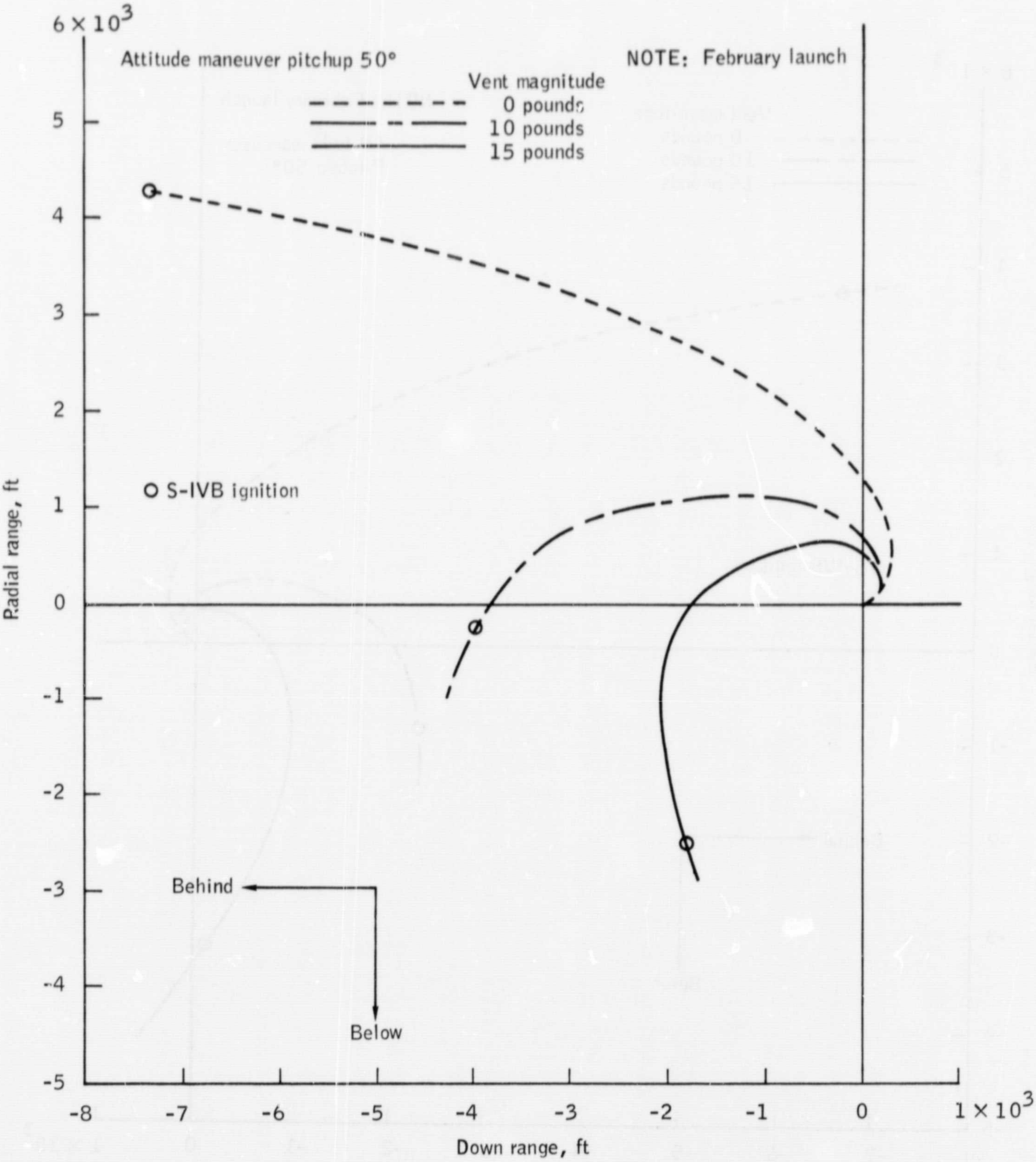
(b) 6-second RCS evasive burn.

Figure 16.- Concluded.



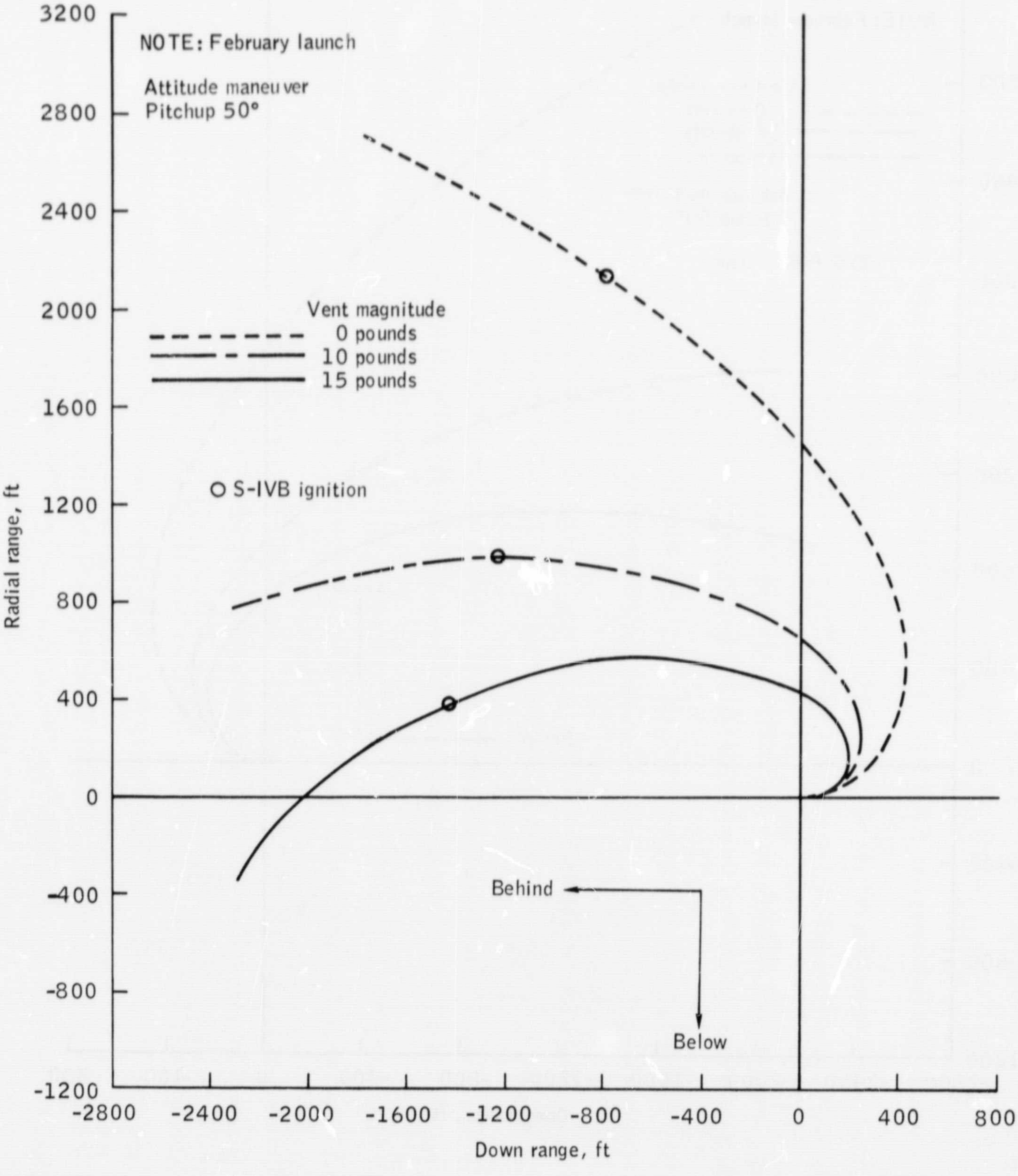
(a) 3-second RCS evasive burn.

Figure 17.- Motion of the CSM/LM relative to the S-IVB for nominal ejection at daylight.



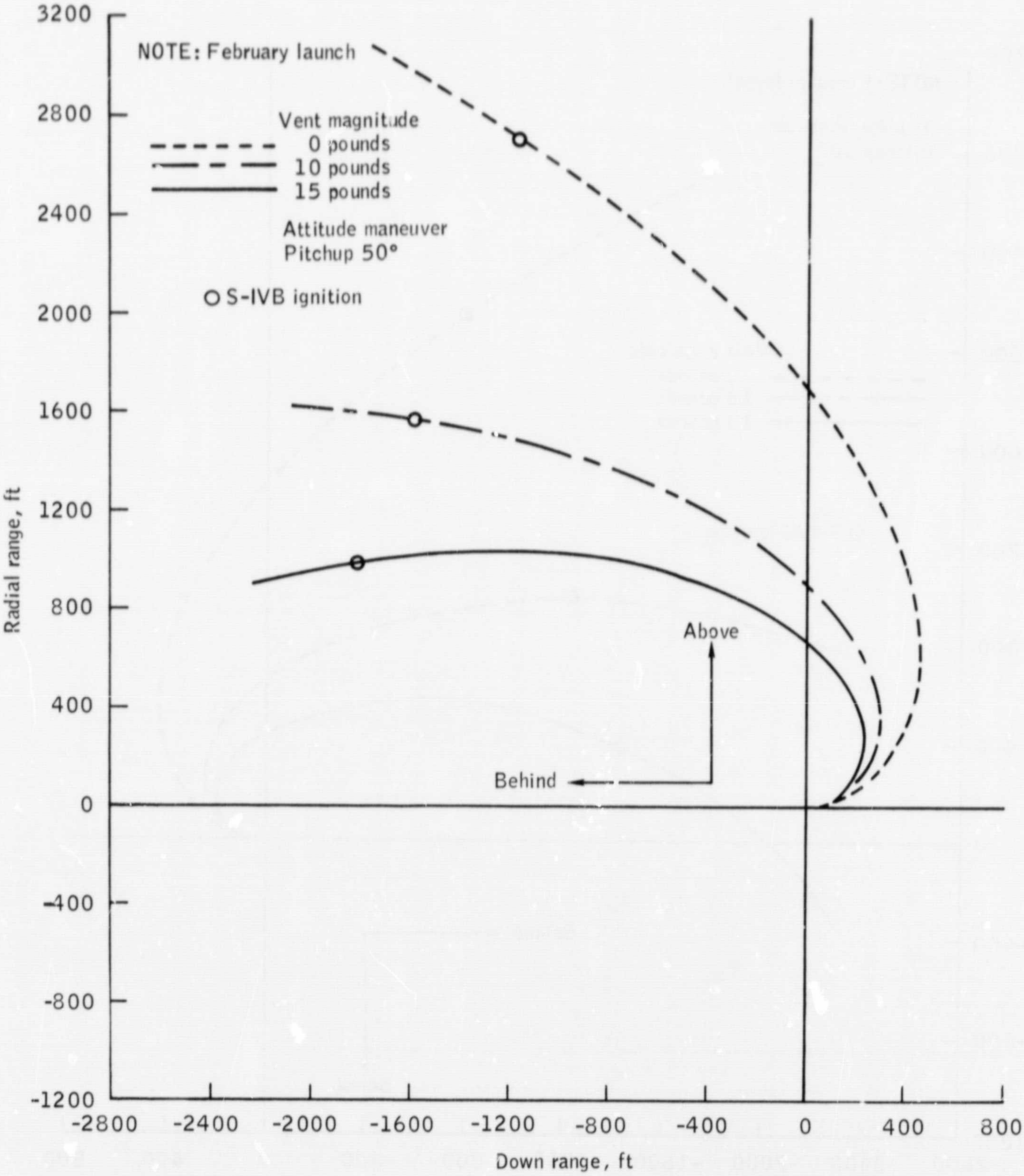
(b) 6-second RCS evasive burn.

Figure 17.- Concluded.



(a) 3-second RCS evasive burn.

Figure 18.- Motion of the CSM/LM relative to the S-IVB for ejection at HAW.



(b) 6-second RCS evasive burn.

Figure 18.- Concluded.

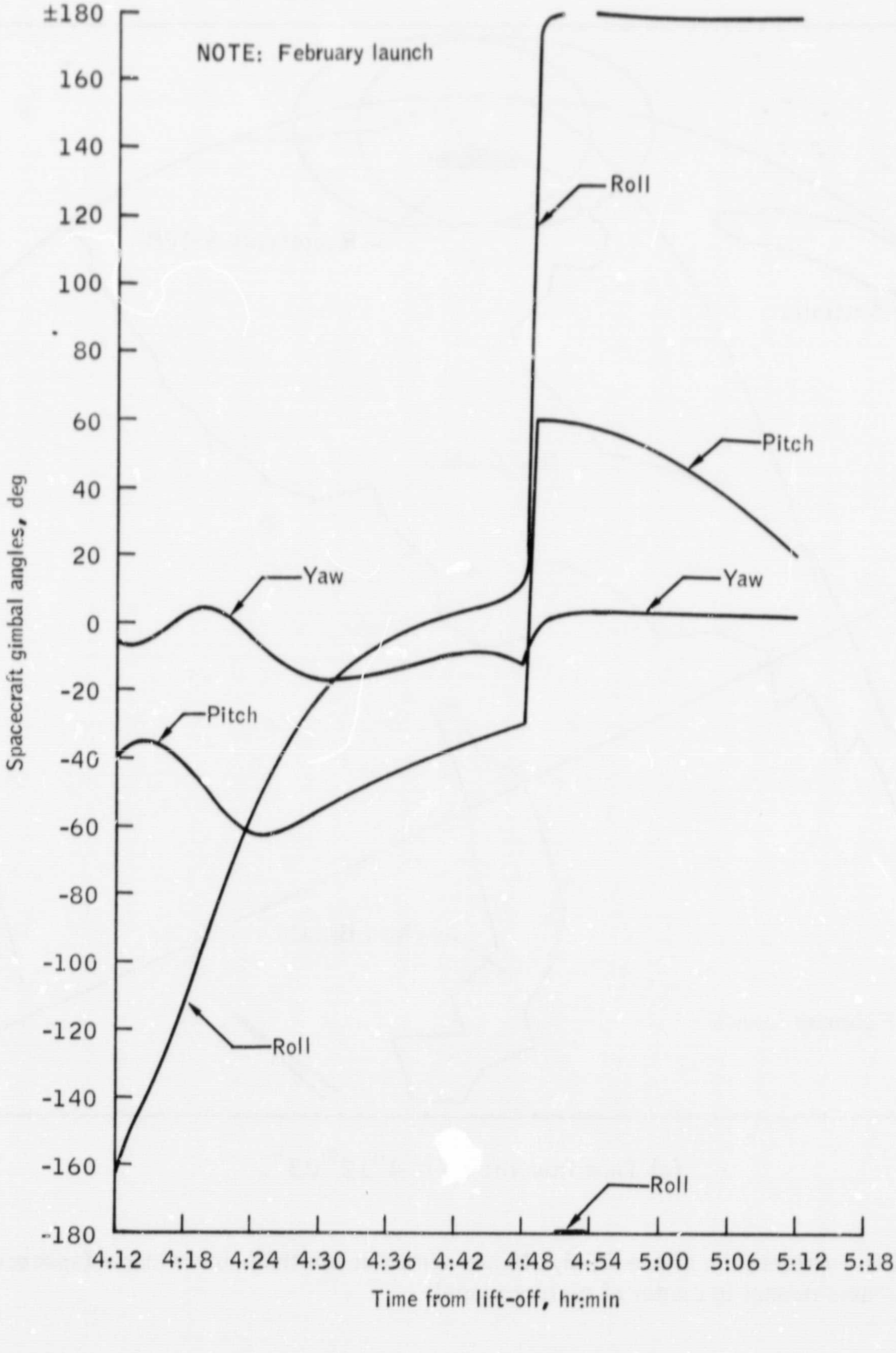
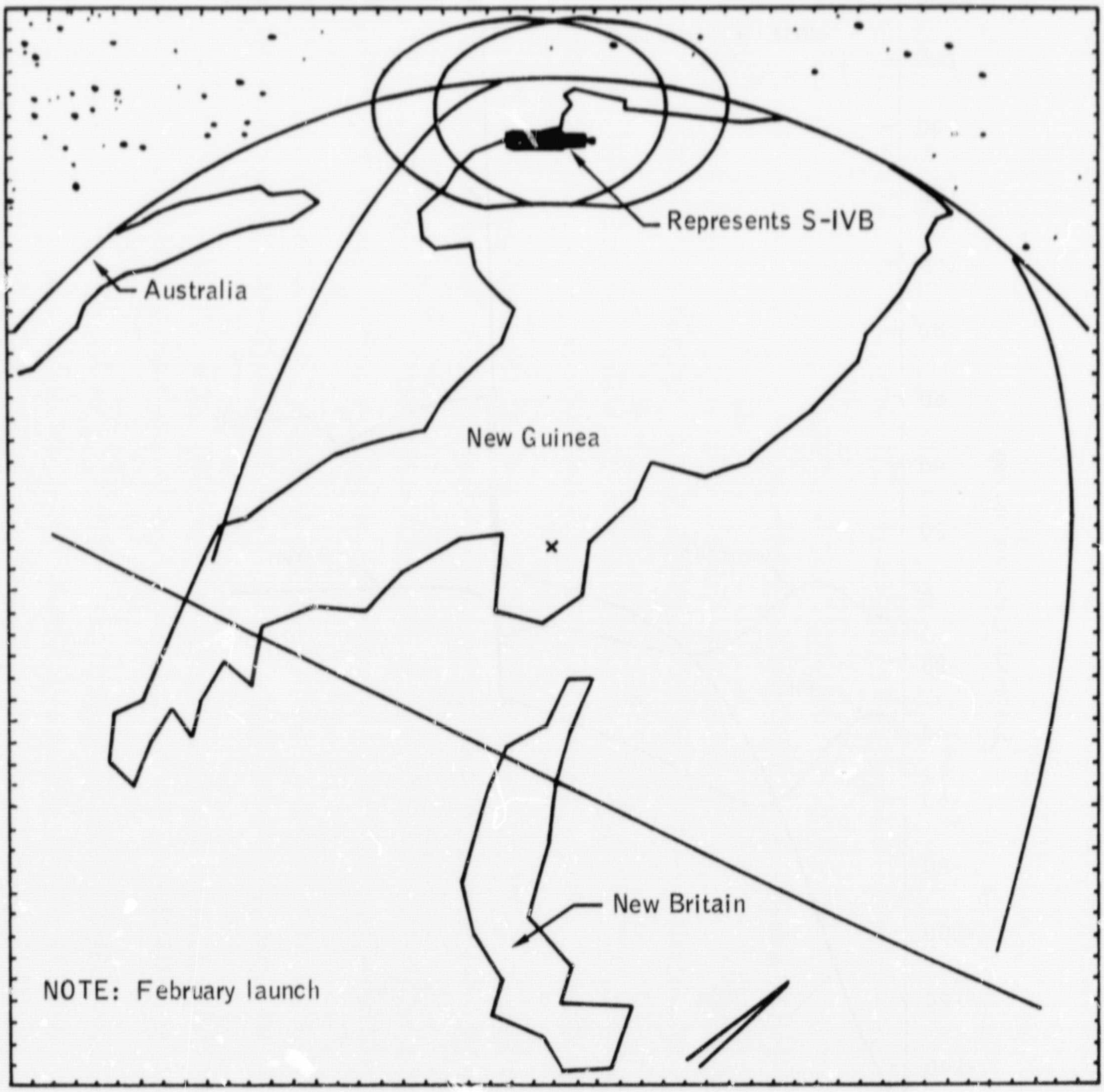
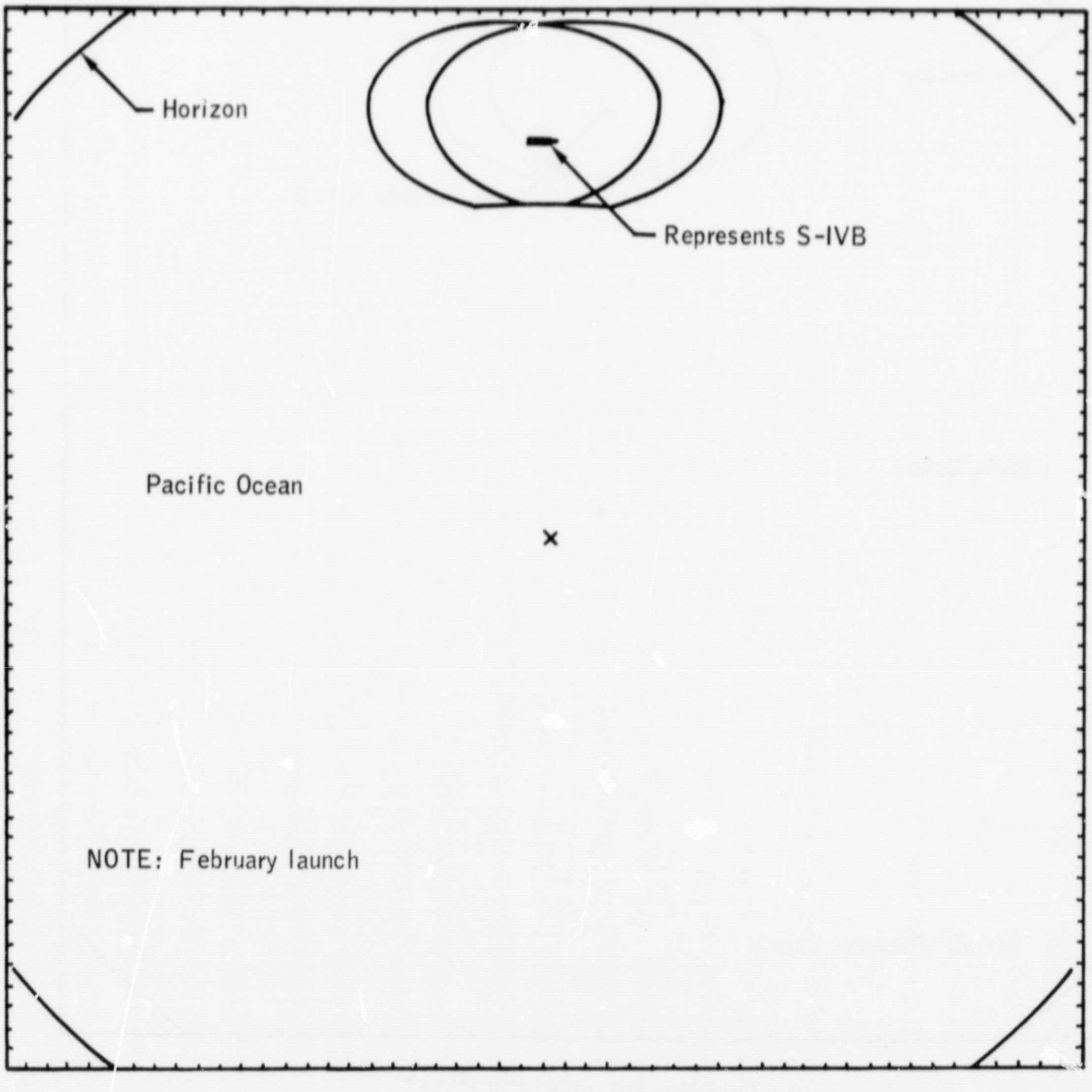


Figure 19.- Spacecraft gimbal angles versus time from lift-off for maintaining visual observation of the S-IVB through the CM hatch window.



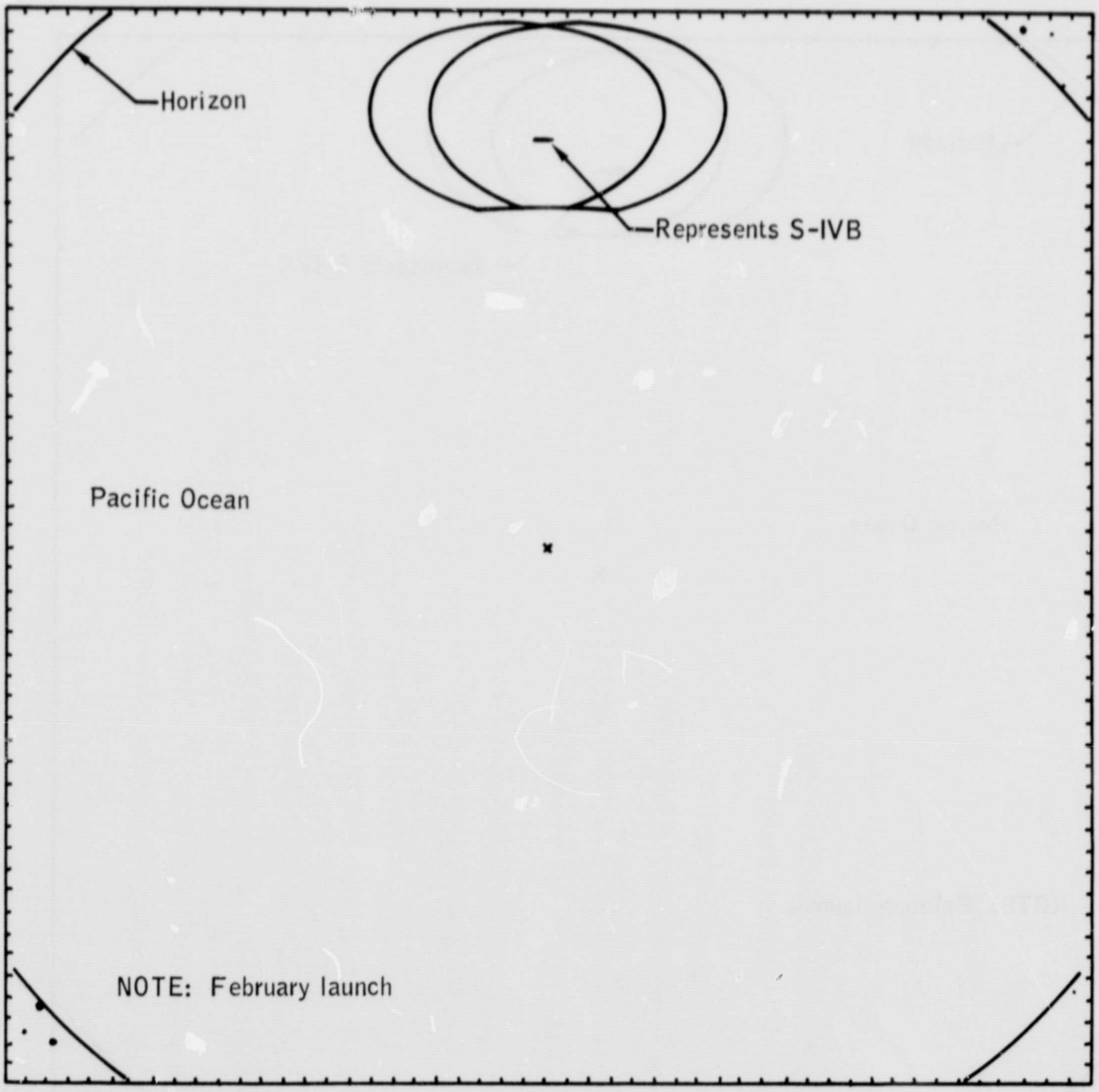
(a) Time from lift-off = $4^h 12^m 03^s$.

Figure 20. - Orientation of the CSM/LM and view through the hatch window (spacecraft plus x-axis normal to center of picture plane).



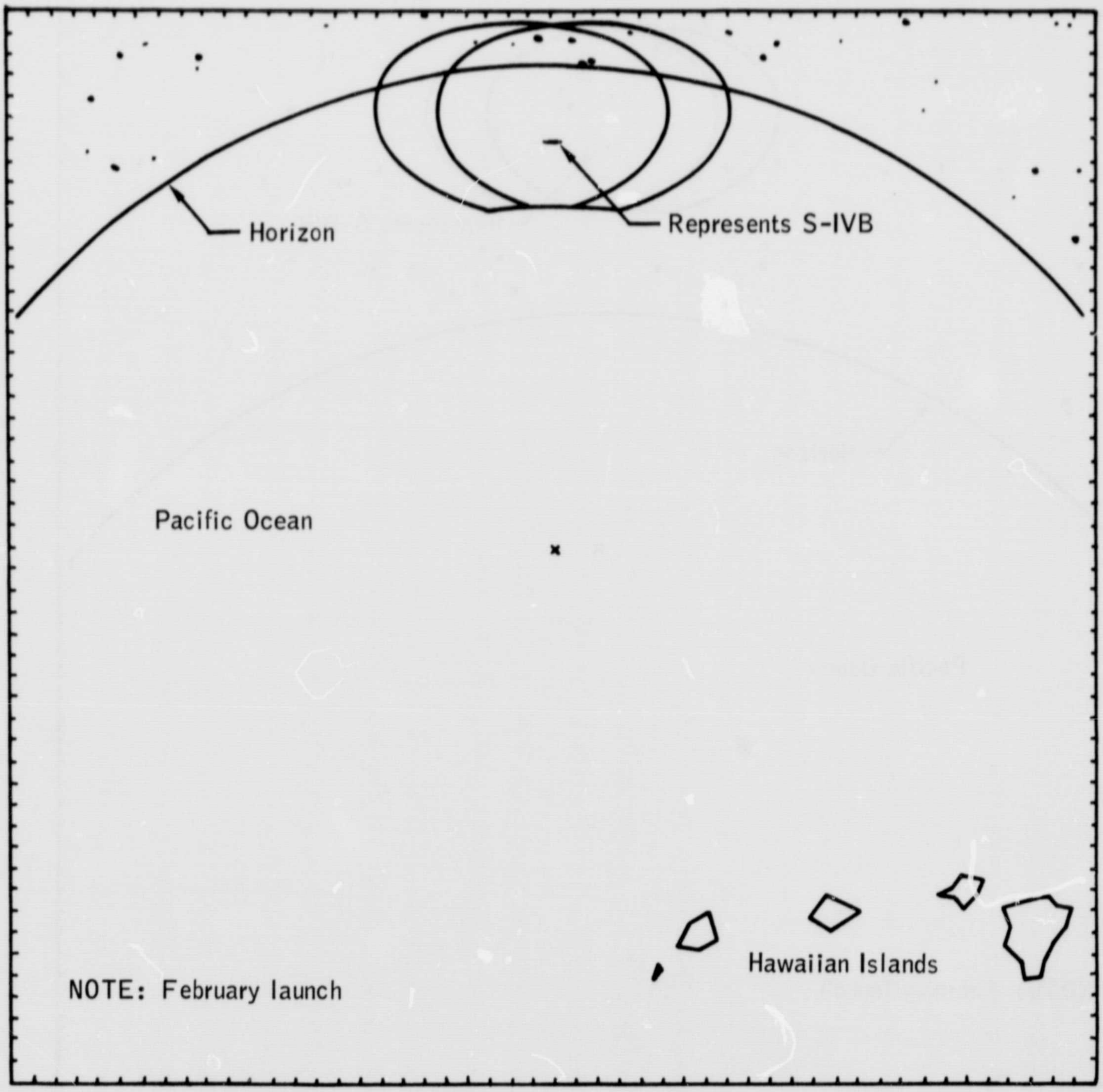
(b) Time from lift-off = $4^h17^m03^s$.

Figure 20.- Continued.



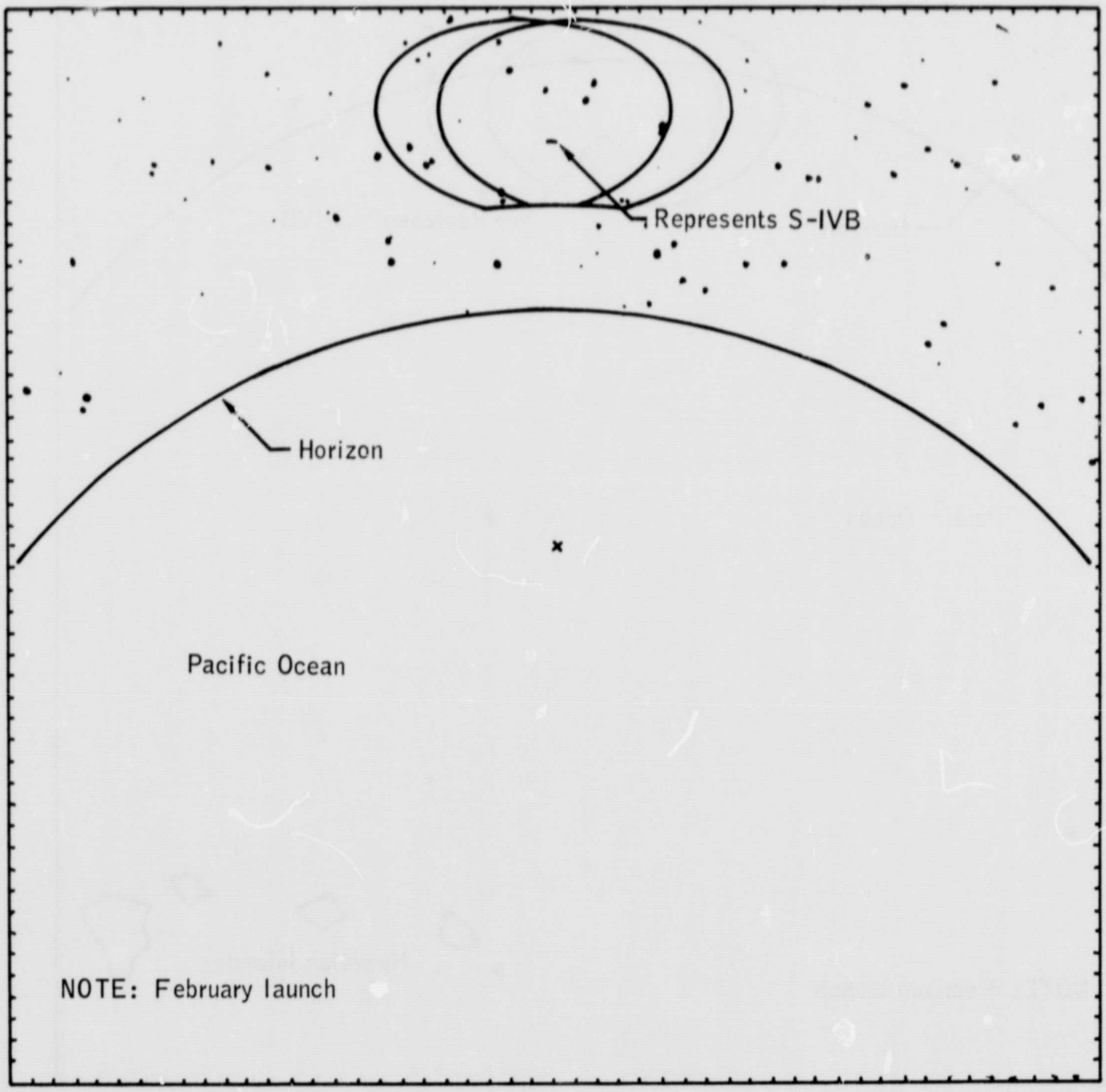
(c) Time from lift-off = $4^h22^m03^s$.

Figure 20.- Continued.



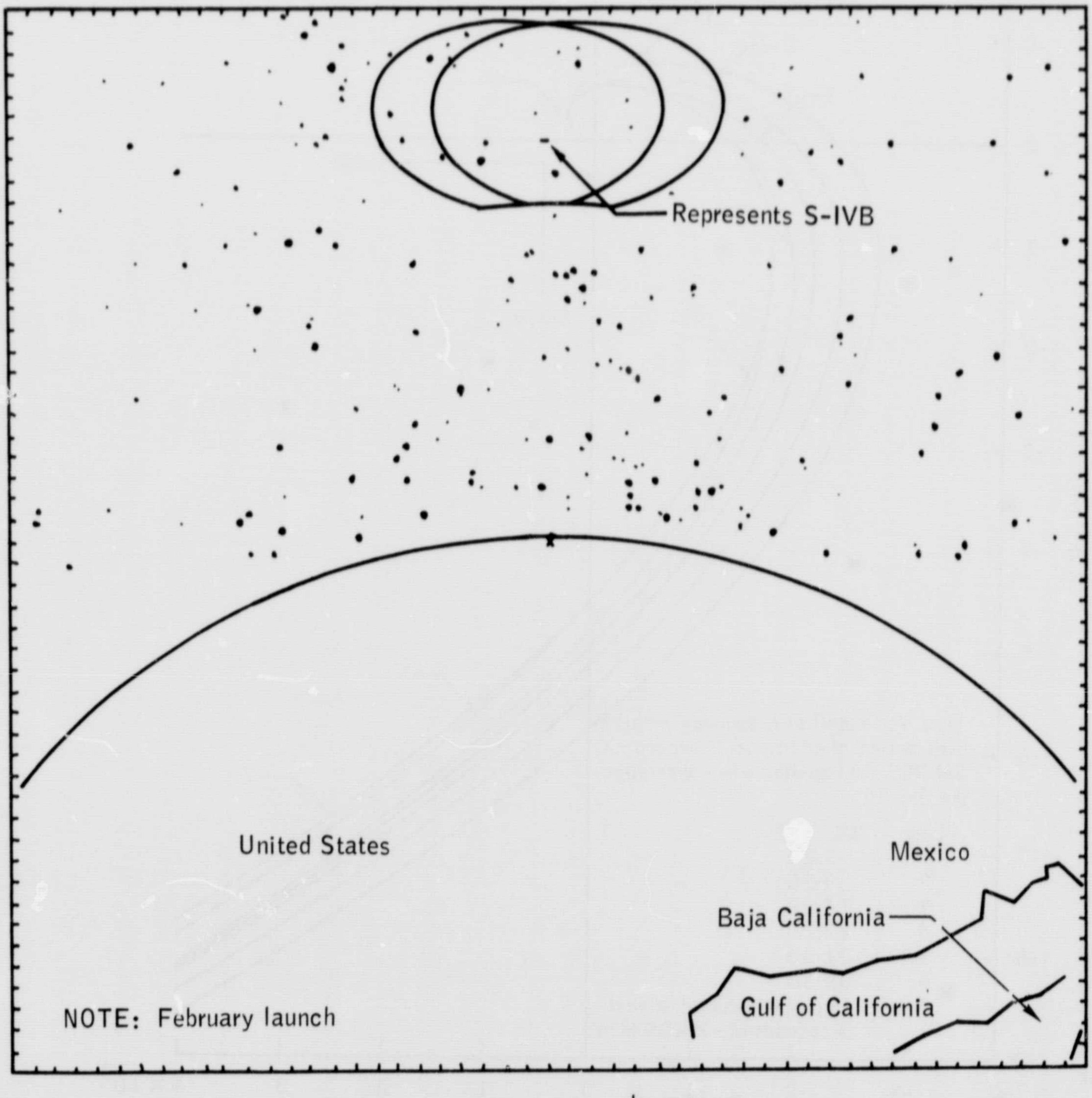
(d) Time from lift-off = $4^h 27^m 03^s$.

Figure 20.- Continued.



(e) Time from lift-off = $4^{h}32^{m}03^{s}$.

Figure 20. - Continued.



(f) Time from lift-off = $4^h37^m03^s$.

Figure 20.- Concluded.

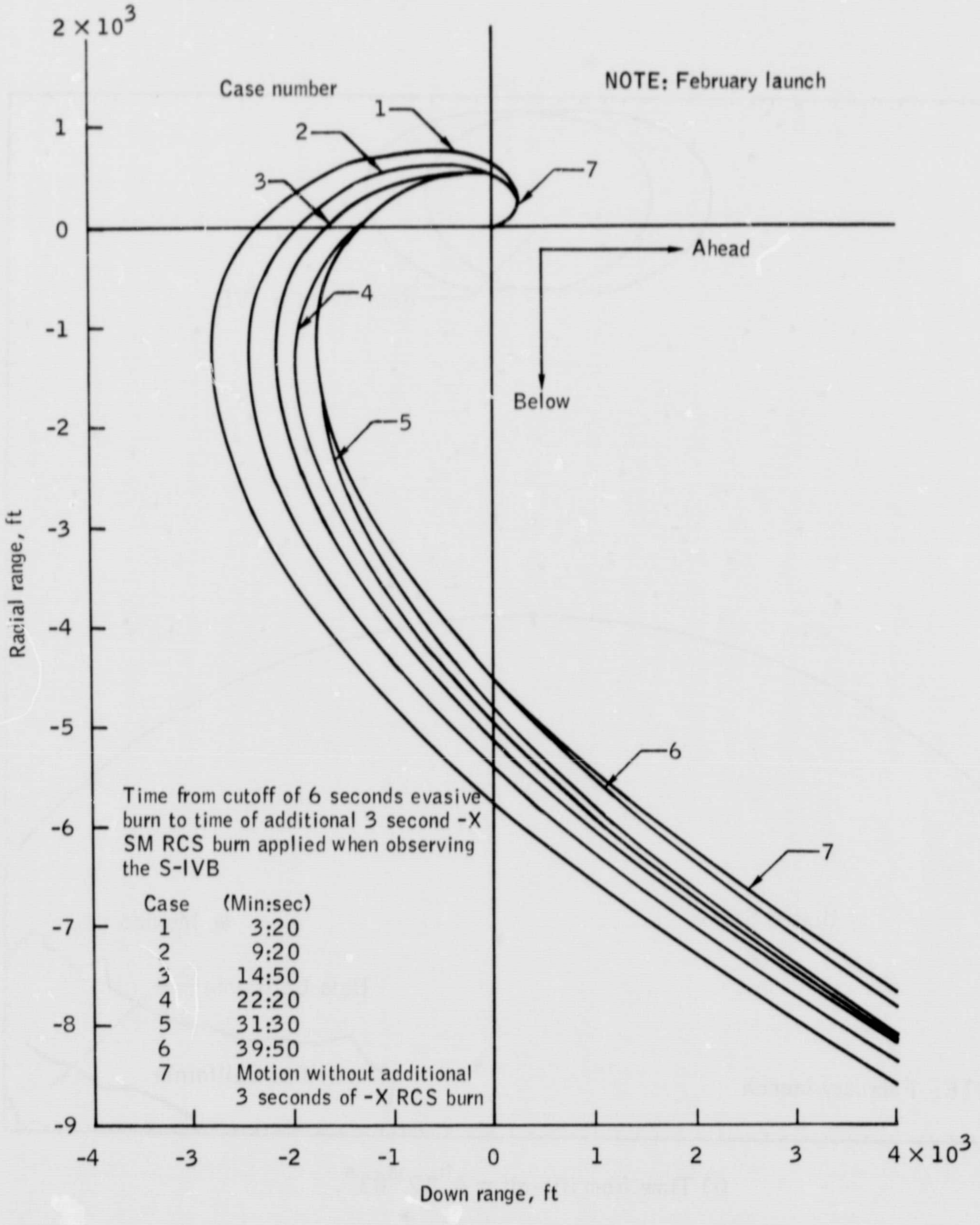
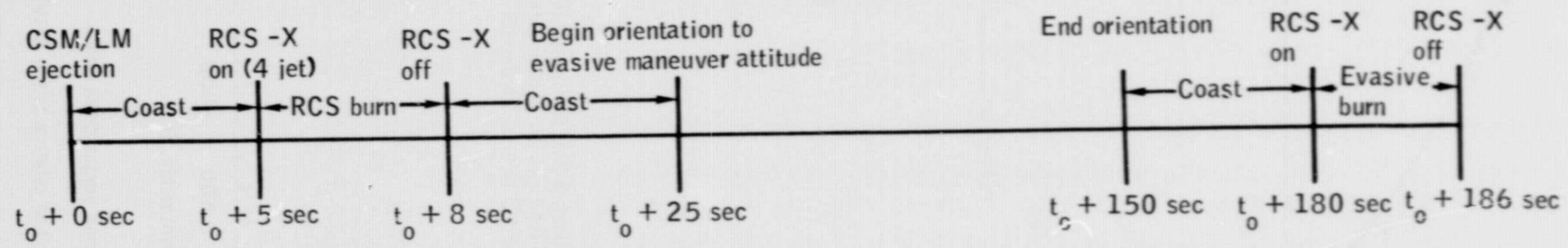
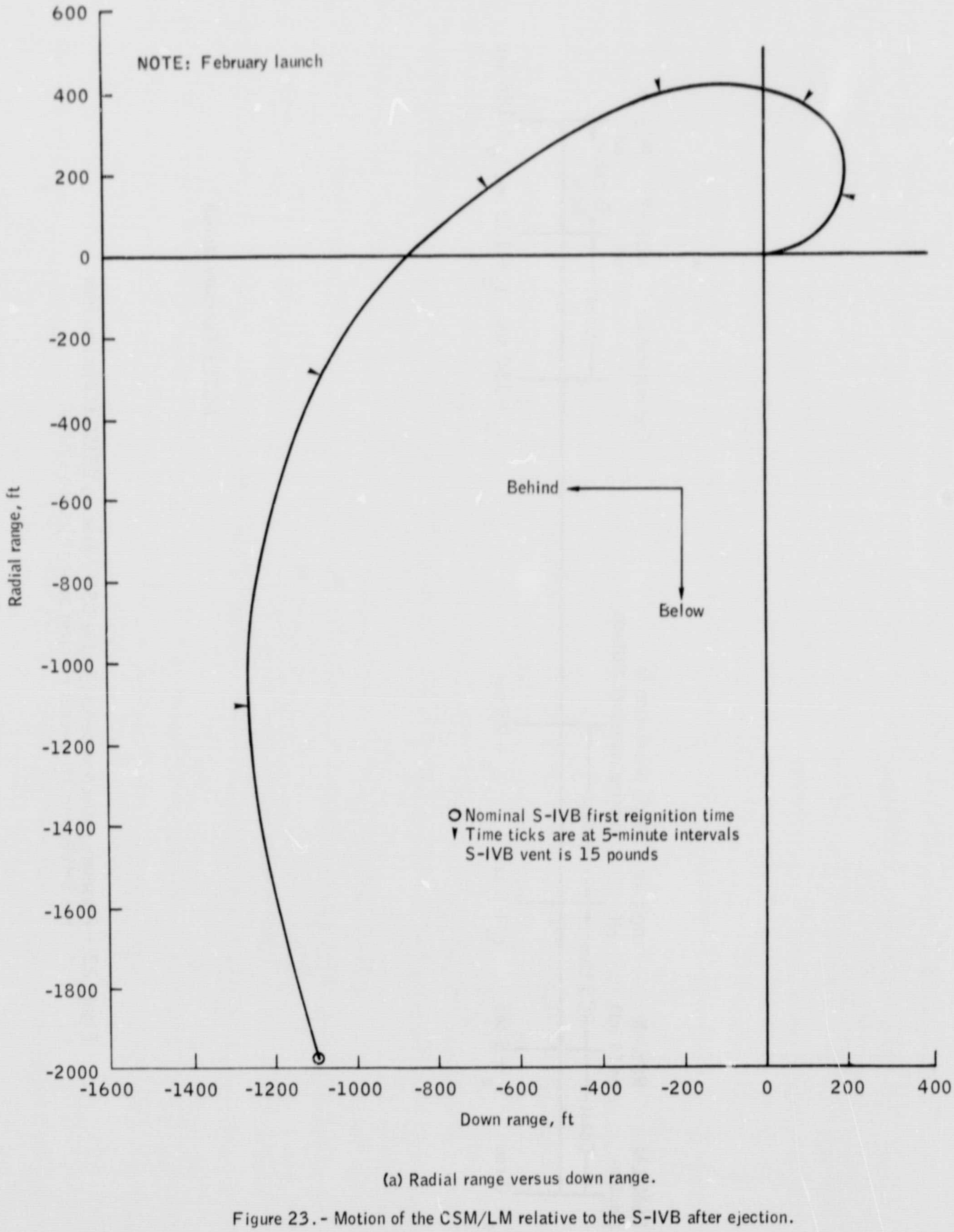


Figure 21.- CSM/LM motion relative to the S-IVB for additional 3 seconds of -X SM RCS thrust applied at various times when observing the S-IVB through the CM hatch window and following the CSM/LM evasive maneuver.



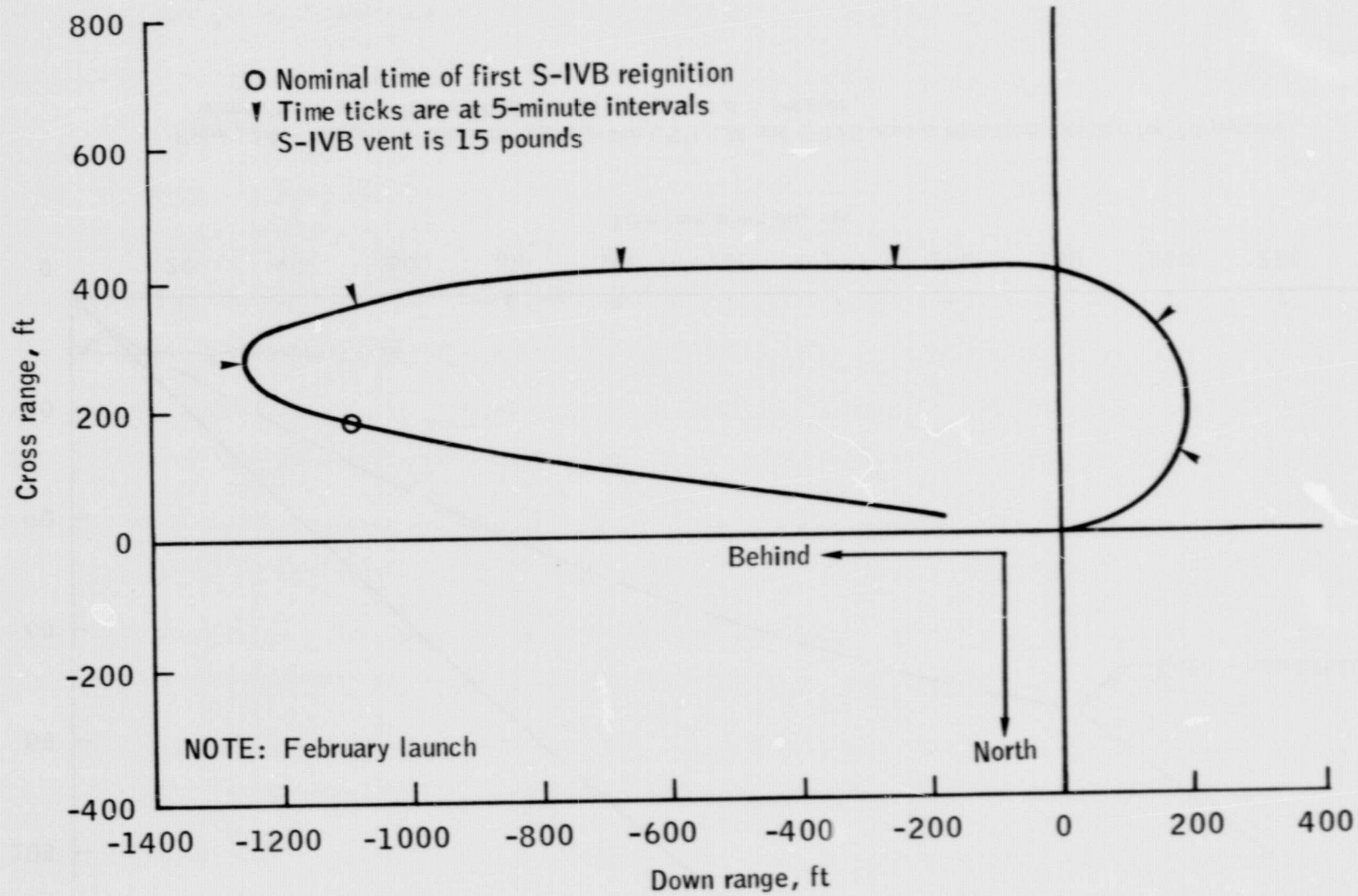
NOTE: February launch

Figure 22.- Presently defined procedure for the CSM following CSM/LM ejection from the S-IVB with 70 percent efficient spring ejection system.



(a) Radial range versus down range.

Figure 23.- Motion of the CSM/LM relative to the S-IVB after ejection.



(b) Down range versus cross range.

Figure 23.- Concluded.

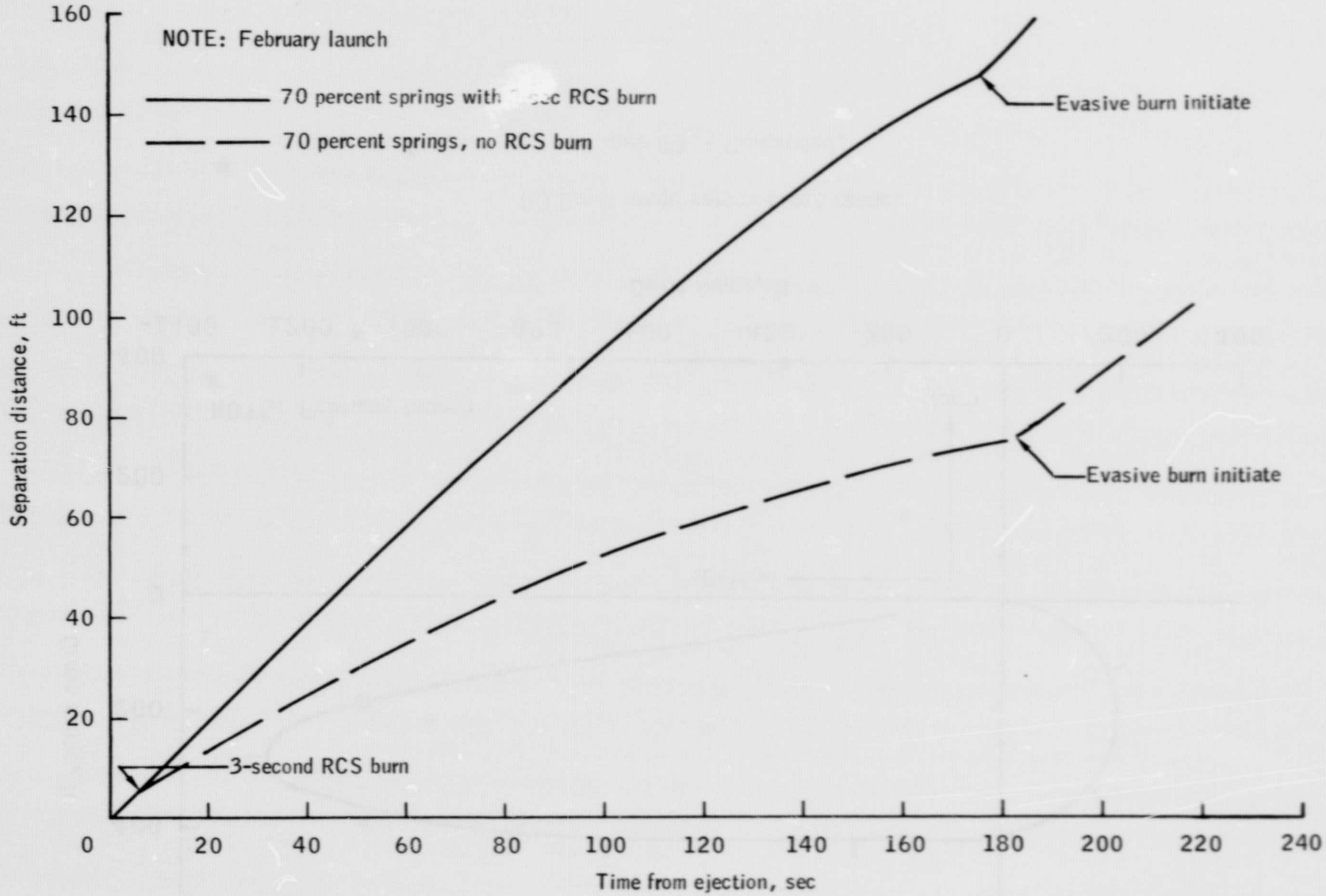
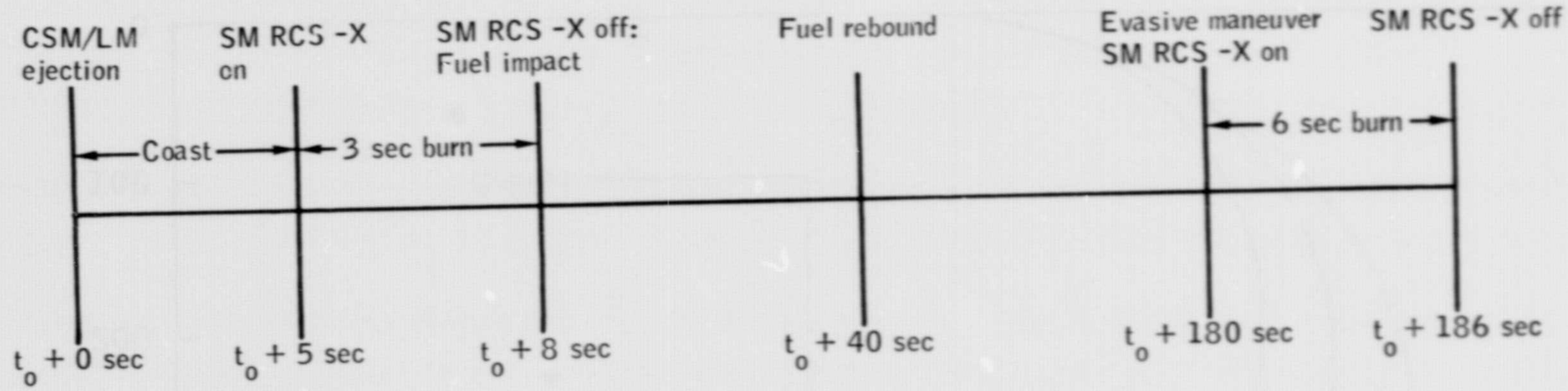
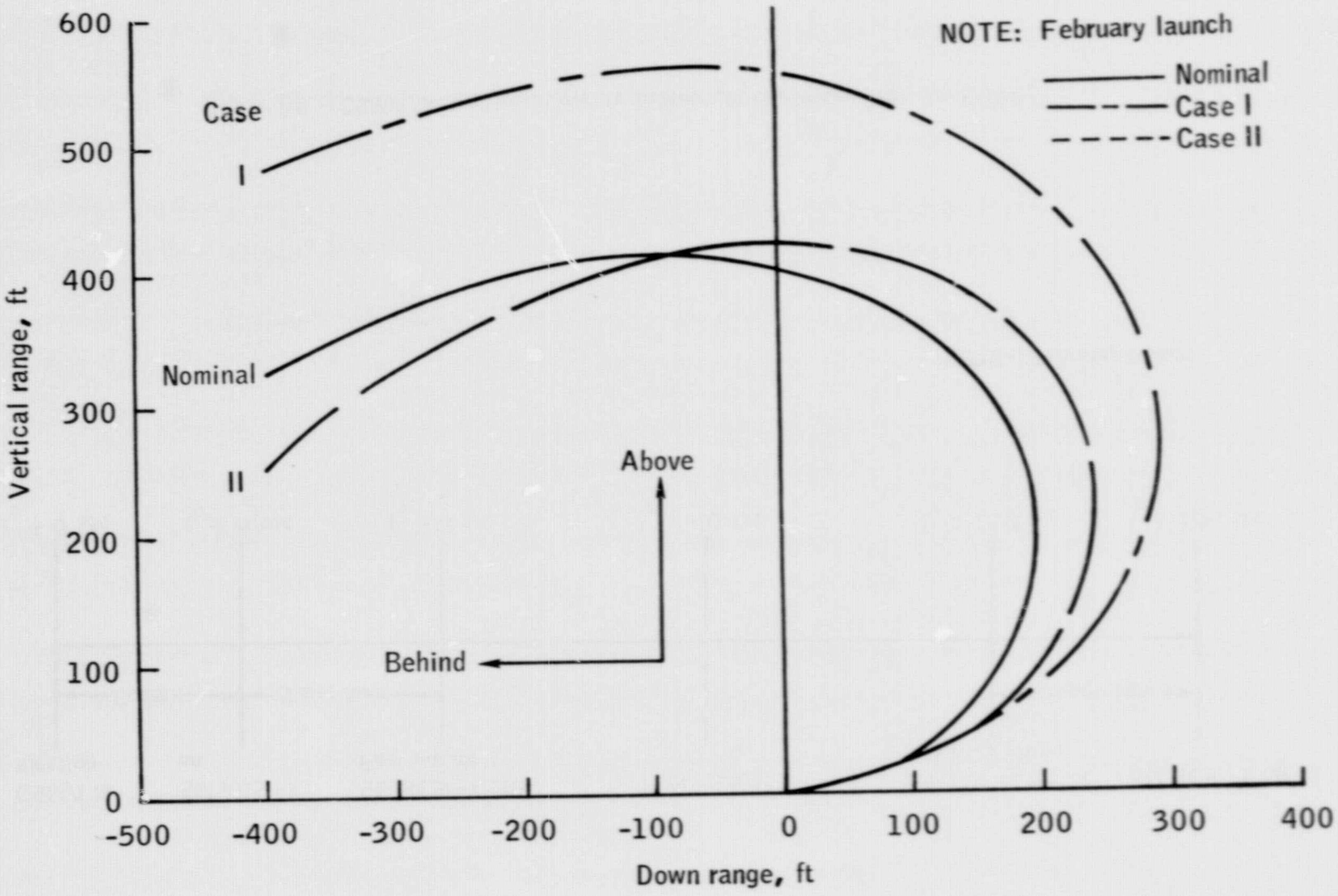


Figure 24.- Separation distance between the CSM/LM and S-IVB versus time from ejection for 70 percent with/without an additional RCS burn at ejection plus 5 seconds.



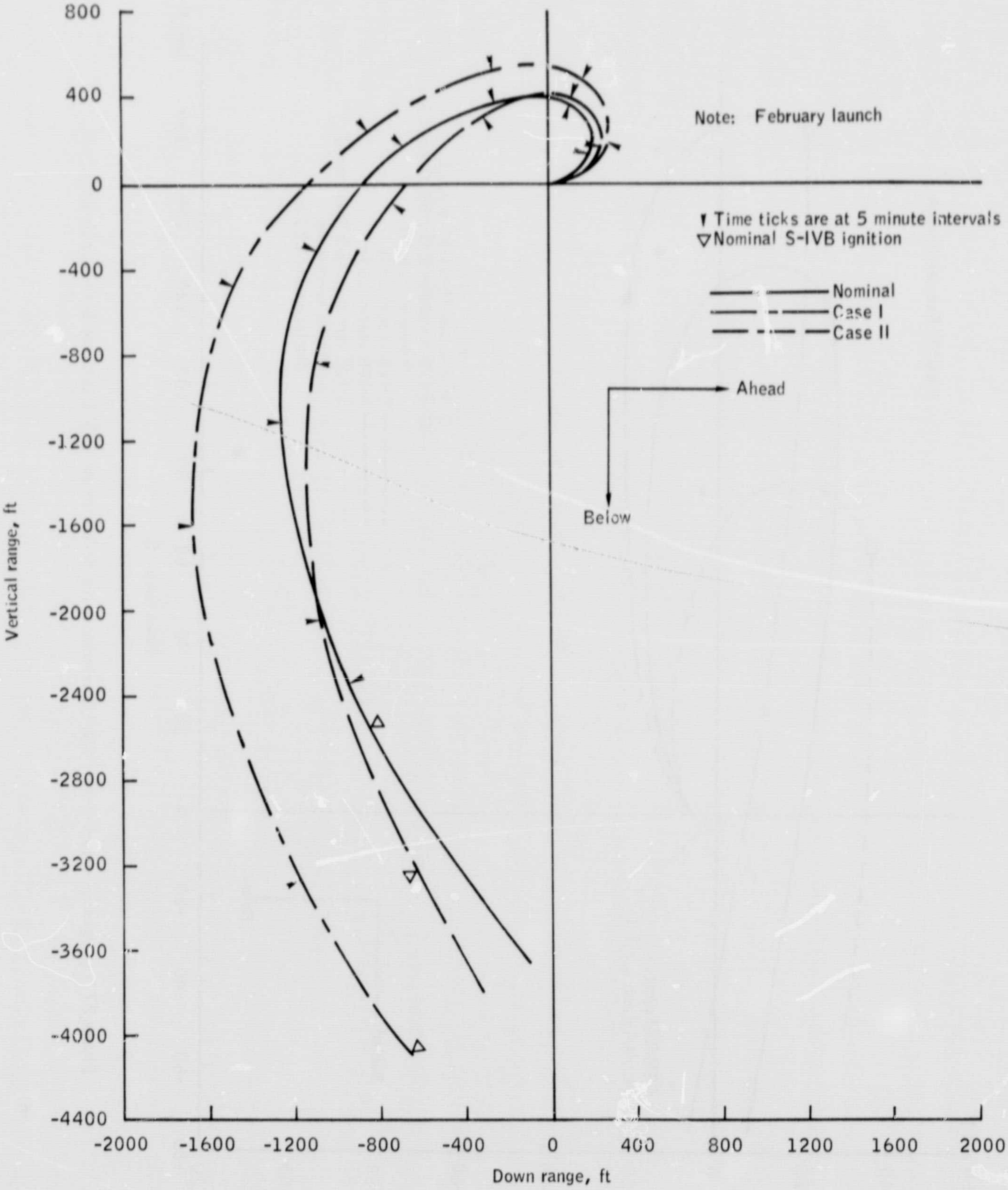
NOTE: February launch

Figure 25.- CSM/LM timeline of events subsequent to ejection from the S-IVB.



(a) Close-in motion.

Figure 26.- Motion of the CSM/LM relative to the S-IVB subsequent to ejection from the S-IVB for various weight configurations (see table).



(b) Long range motion subsequent to ejection from the S-IVB (see table).

Figure 26.- Concluded.

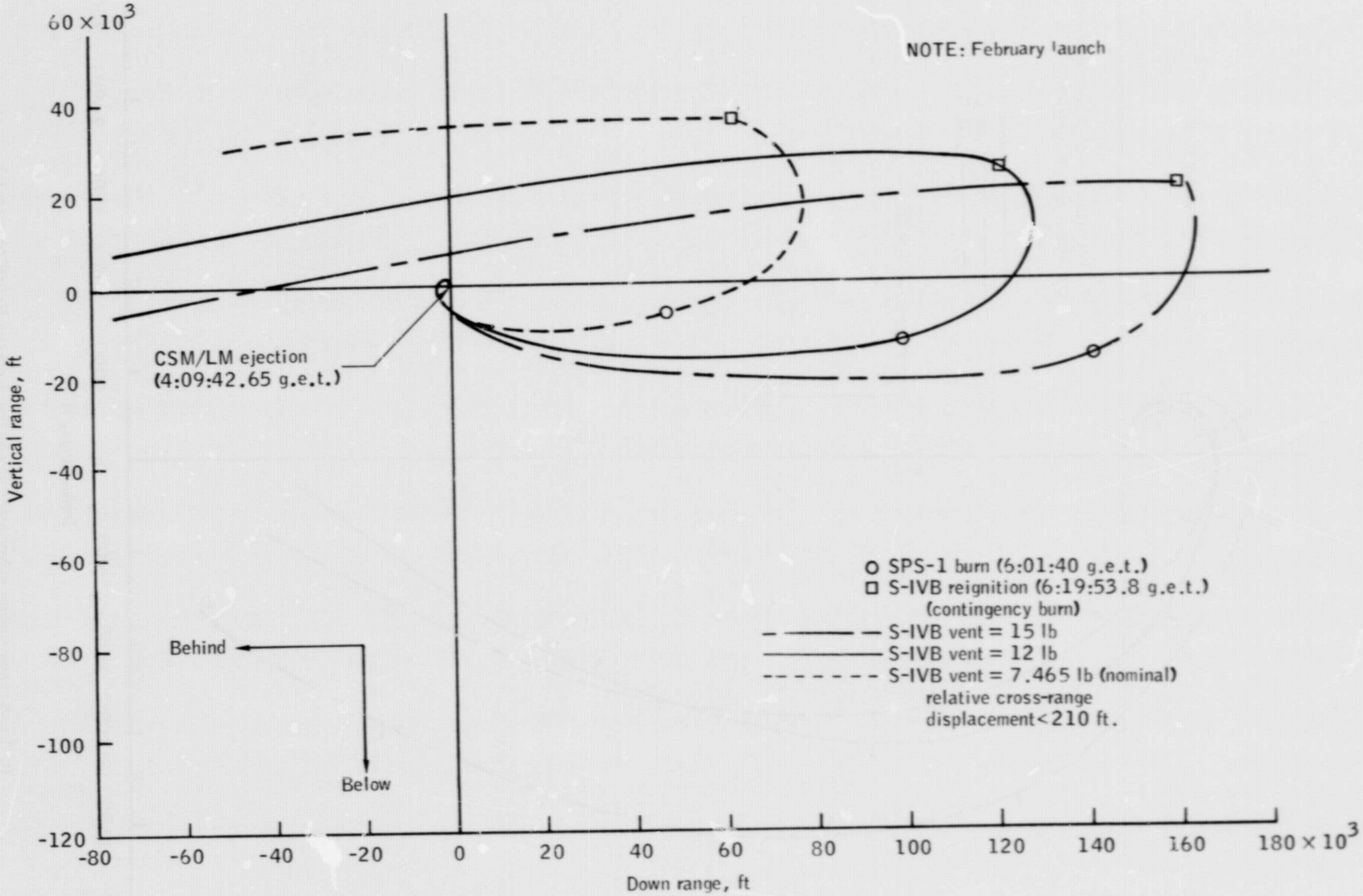


Figure 27.- Long-range motion of the CSM/LM relative to the S-IVB for the SPS-1 burn and S-IVB contingency burn.

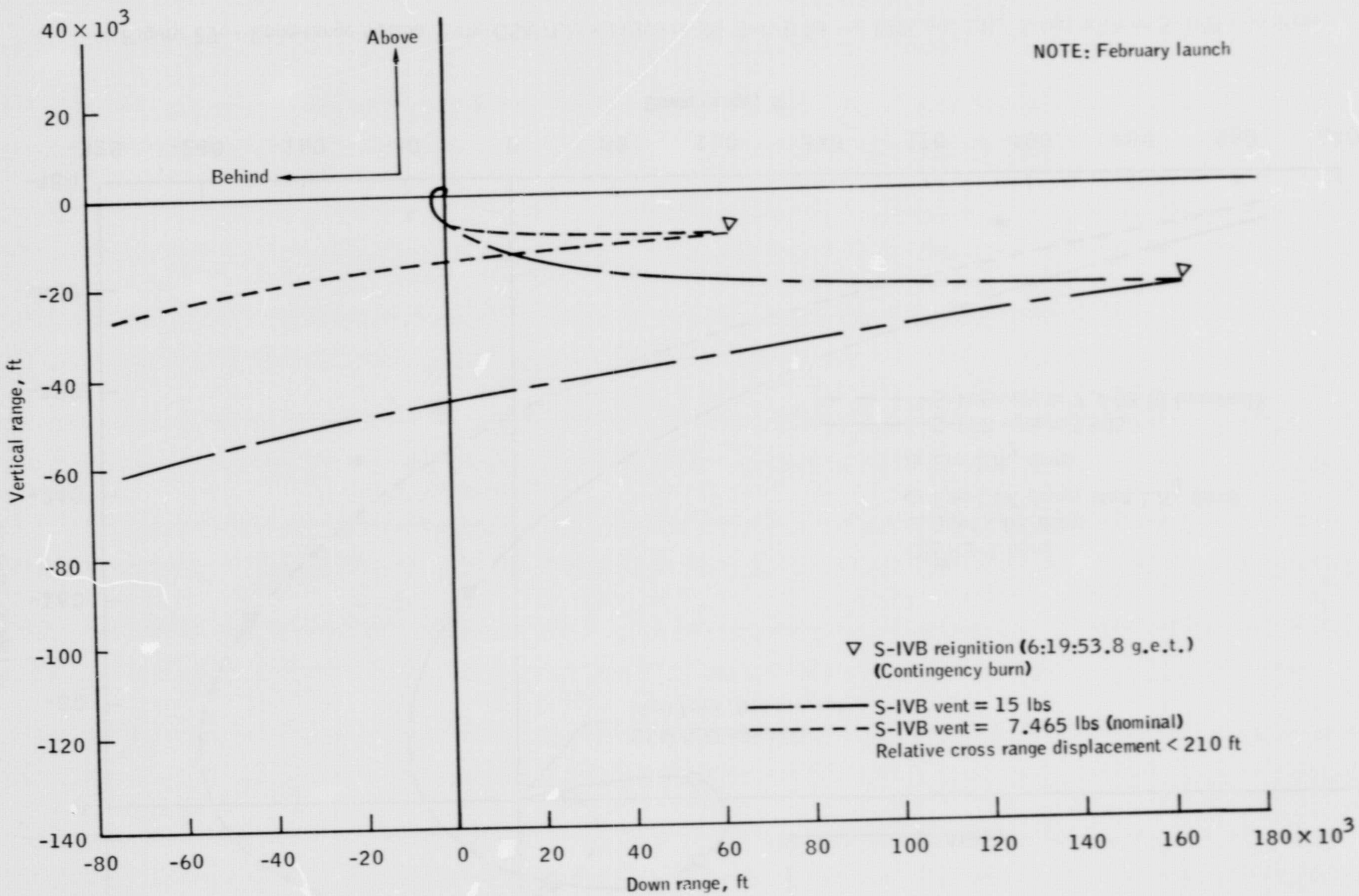


Figure 28.- Long range motion of the CSM/LM relative to the S-IVB for no SPS-1 burn and the S-IVB contingency burn.

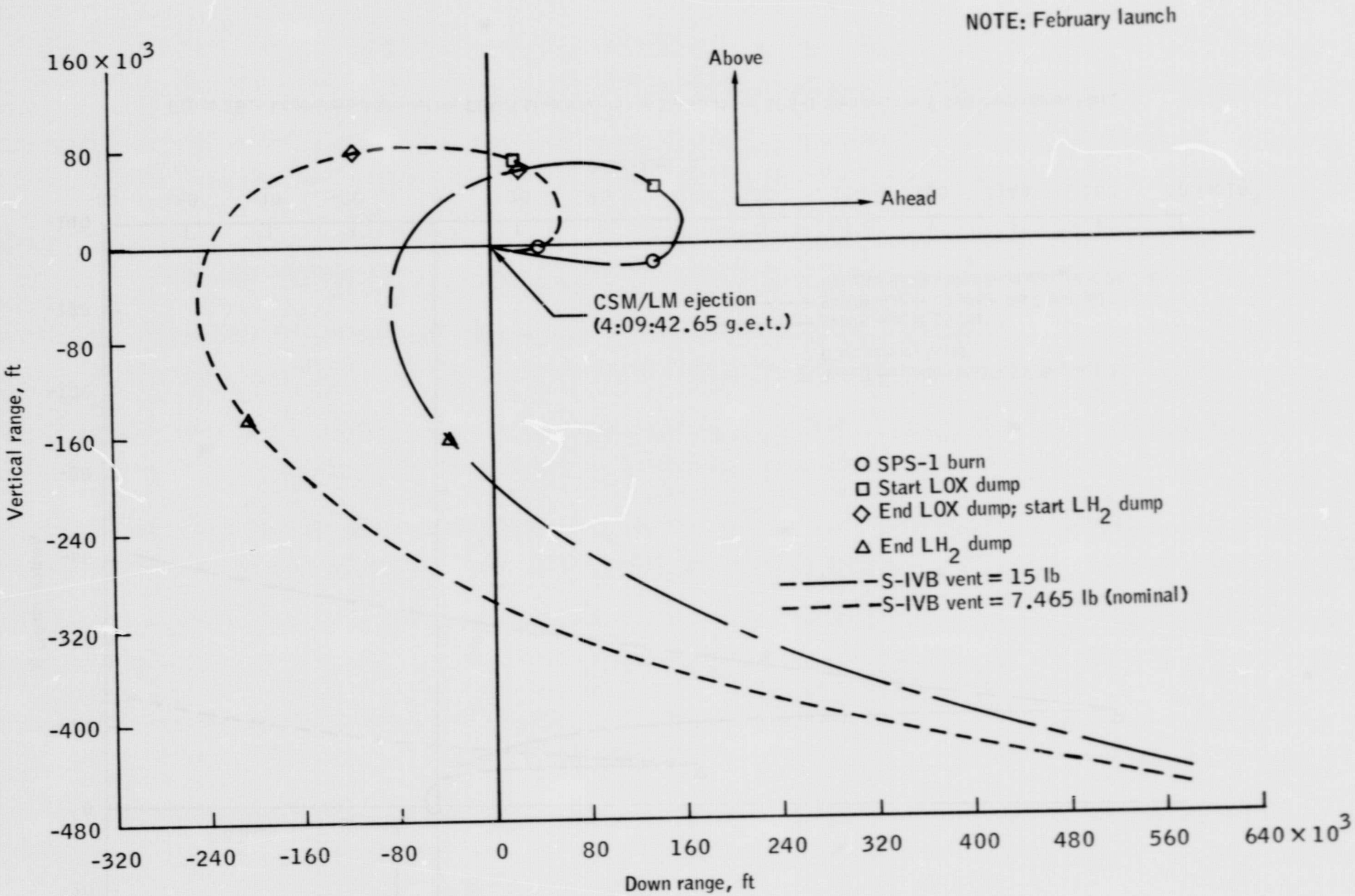


Figure 29.- Long-range motion of the CSM/LM relative to the S-IVB for the LOX and LH_2 dumps with no S-IVB reignition.

Region	Time duration, g.e.t., hr:min:sec	
	Begin	End
I	3:59:17	4:25:00
	5:06:40	5:53:38
II	4:20:00	5:02:24
III	5:02:24	5:21:00

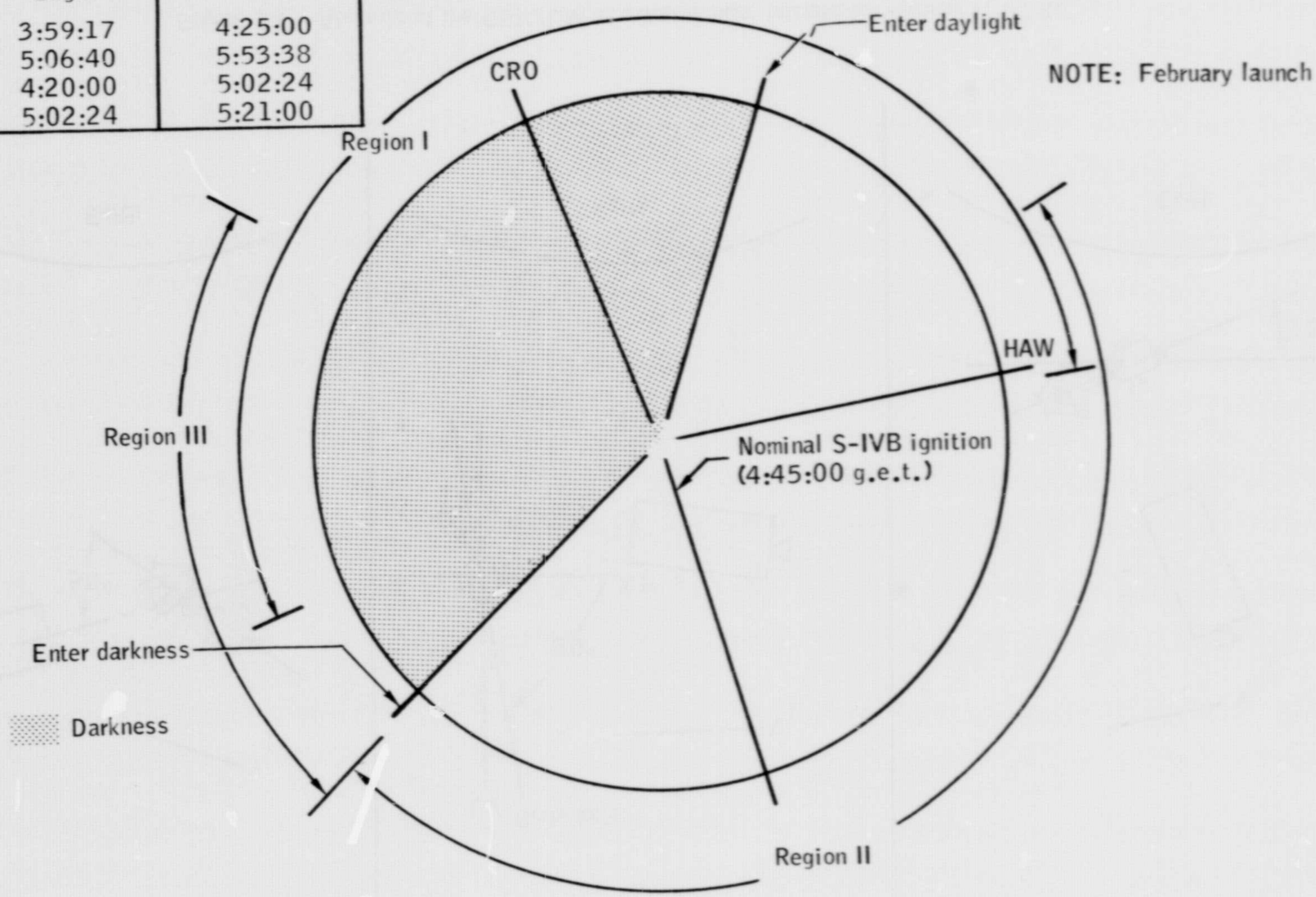


Figure 30.- Definition of ejection regions for CSM/LM ejections from the S-IVB during one complete revolution after daylight.

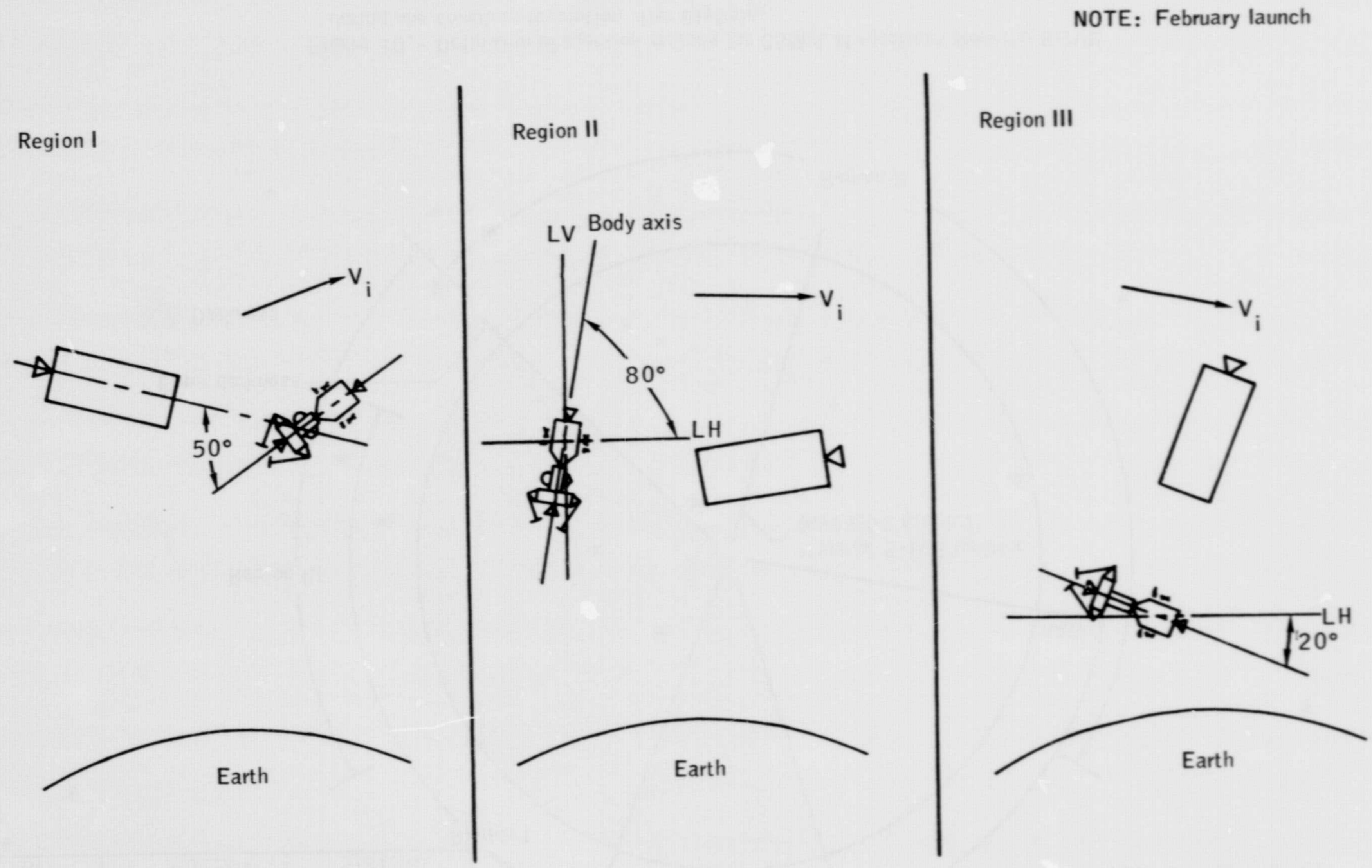
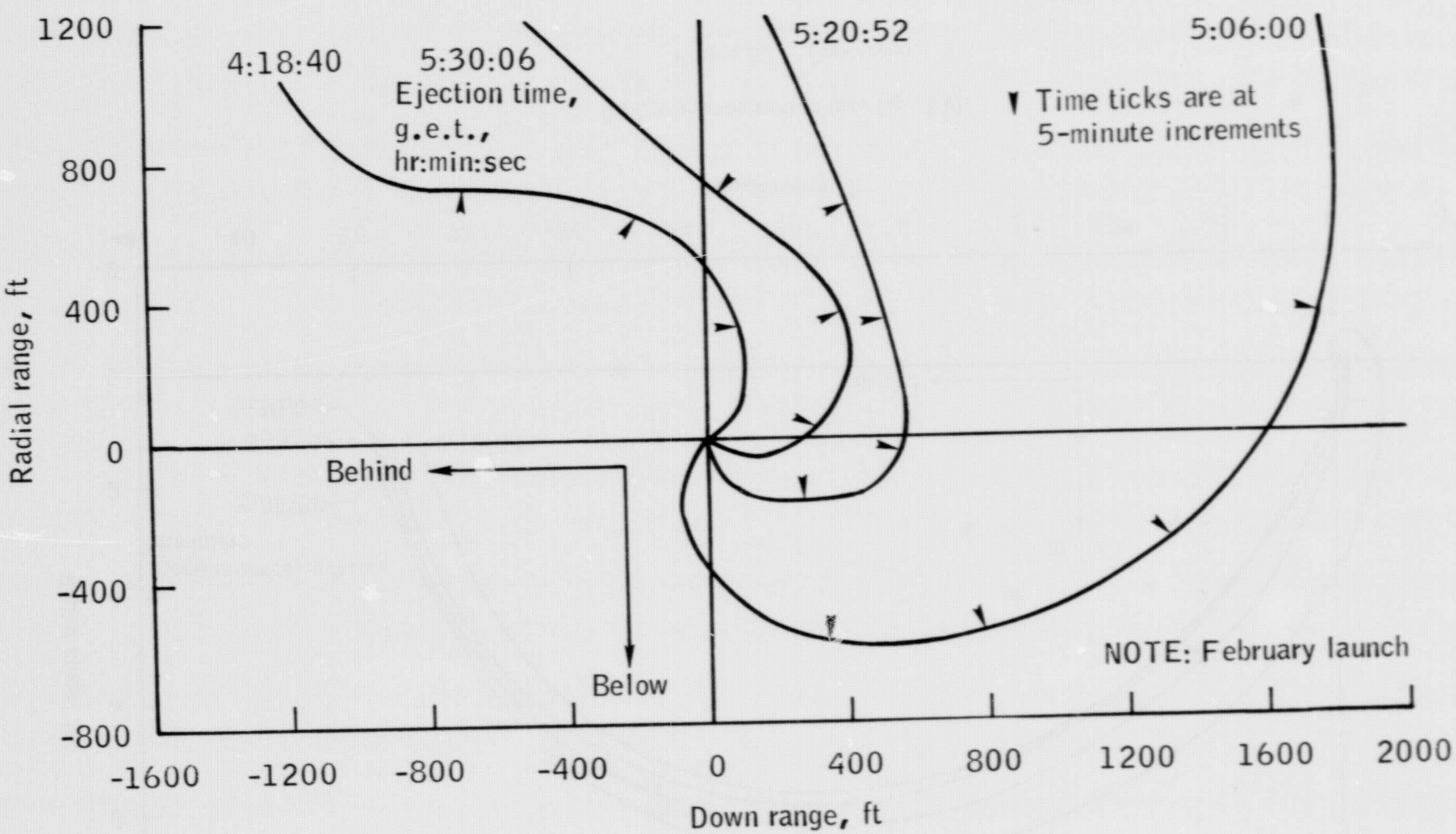
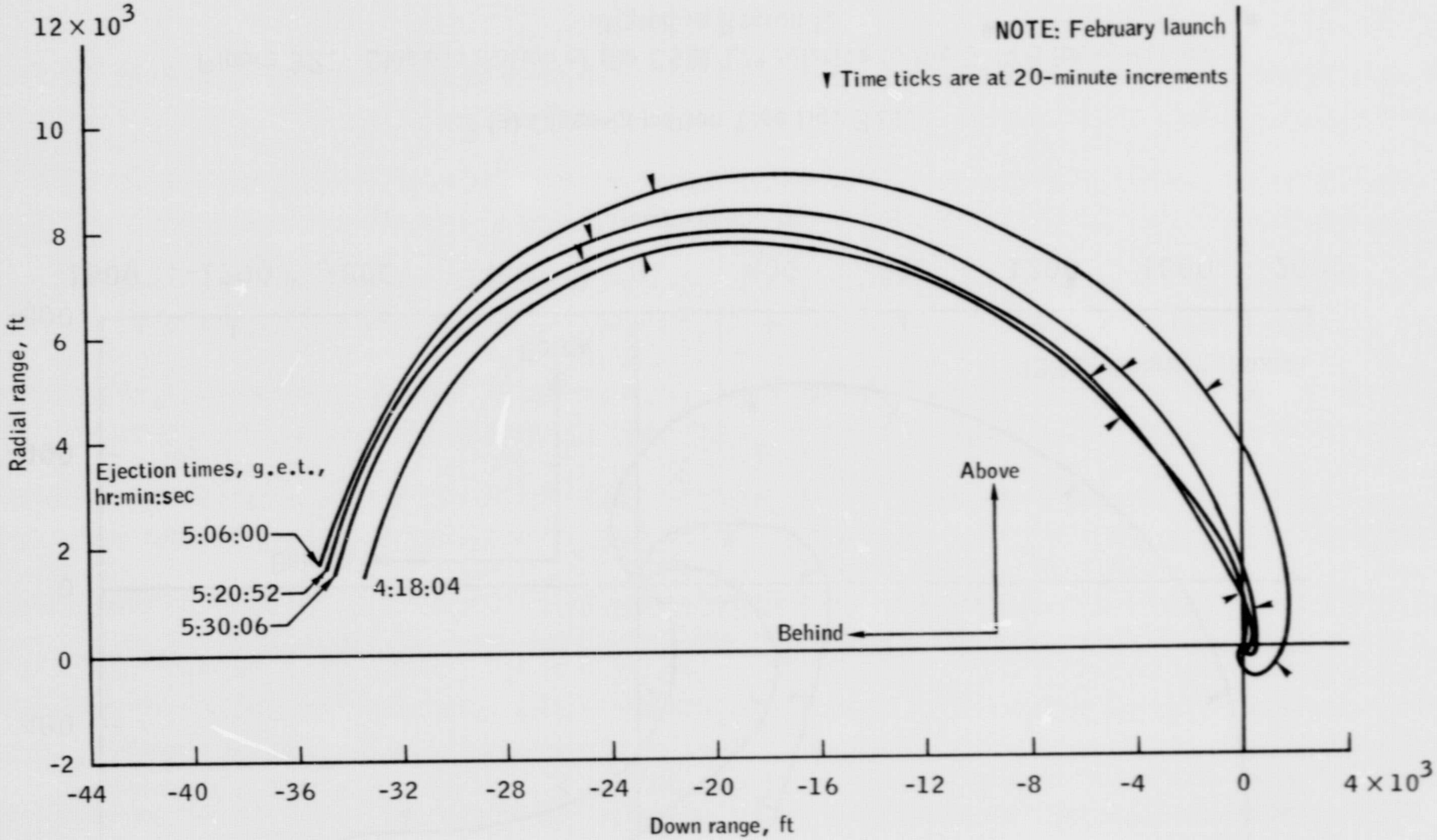


Figure 31.- Attitude of the CSM/LM at evasive burn initiate for regions I, II, III.



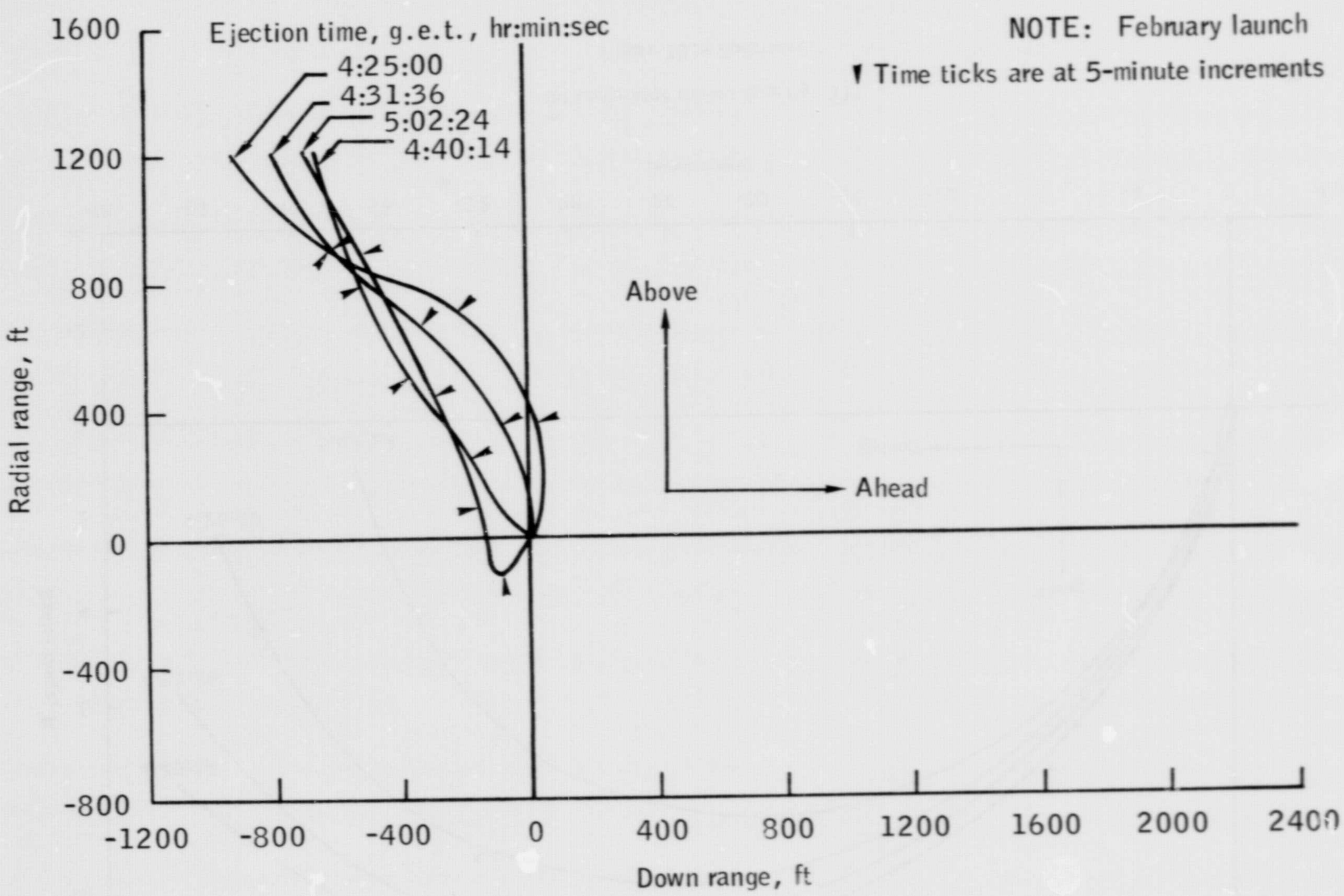
(a) Close-in motion (see fig. 31).

Figure 32.- Close-in motion of the CSM/LM relative to the S-IVB for ejections initiated in Region I.



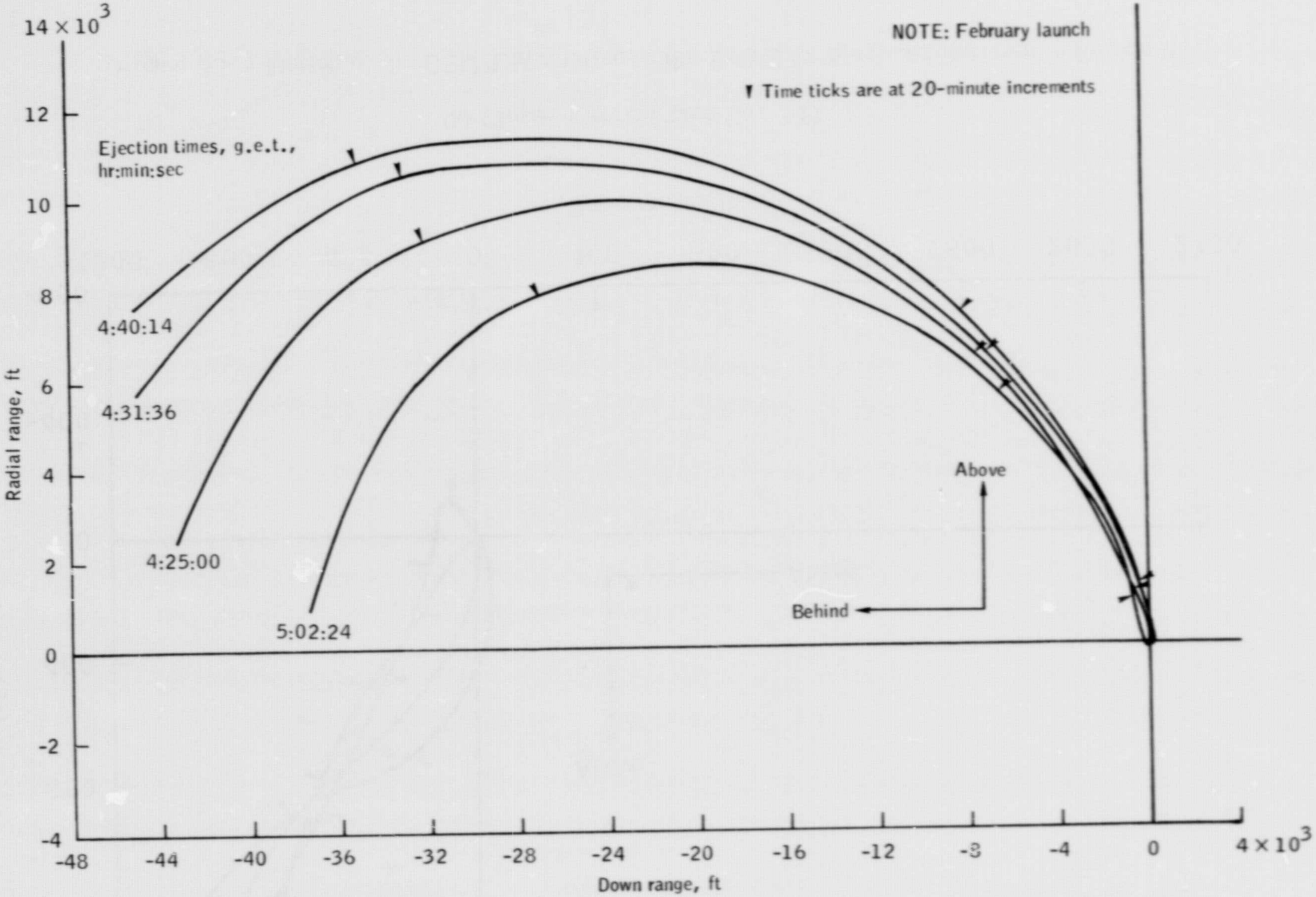
(b) Long-range motion (see fig. 31).

Figure 32.- Concluded.



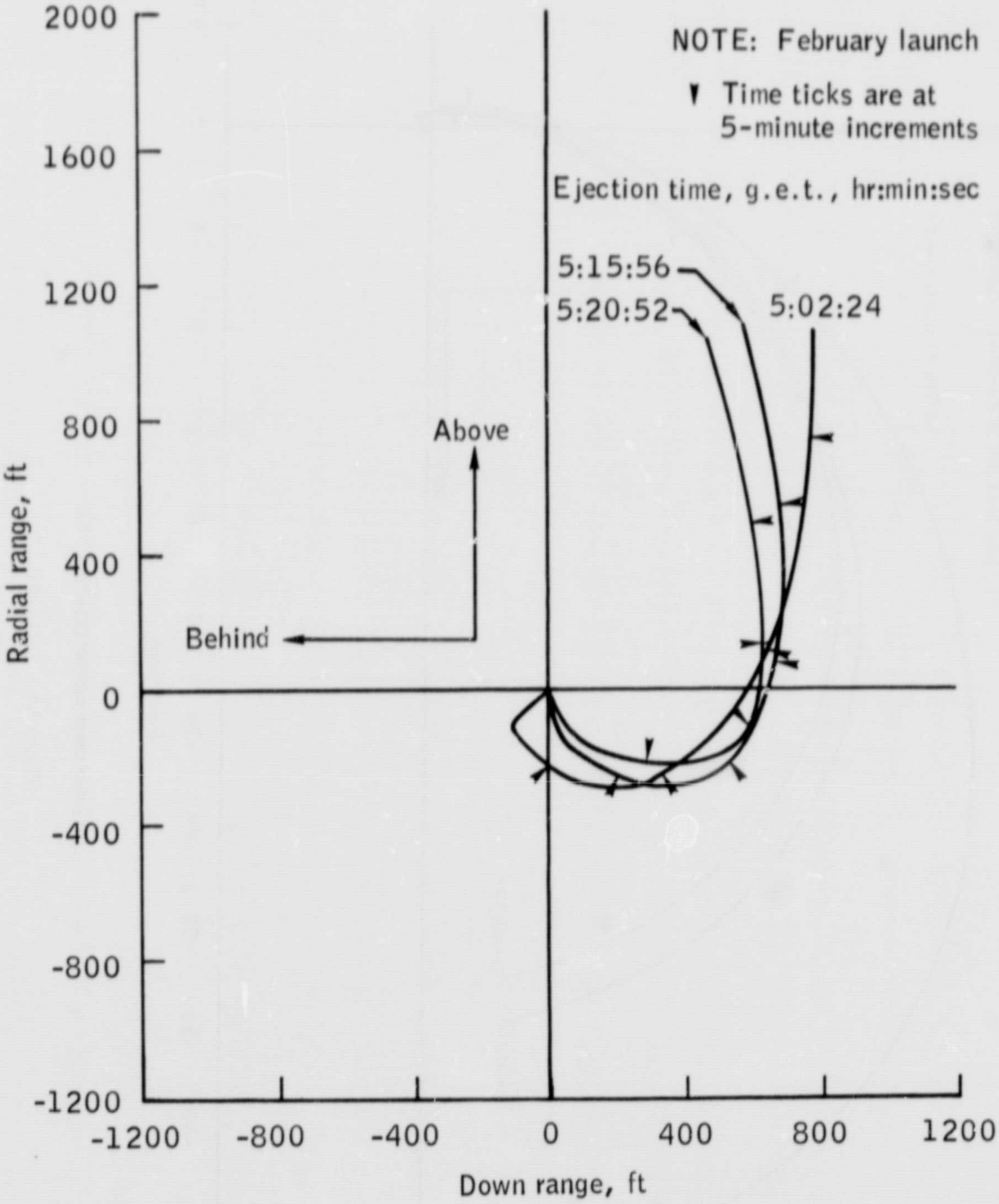
(a) Close-in motion (see fig. 31).

Figure 33.- Motion of the CSM/LM relative to the S-IVB for ejections initiated in Region II.



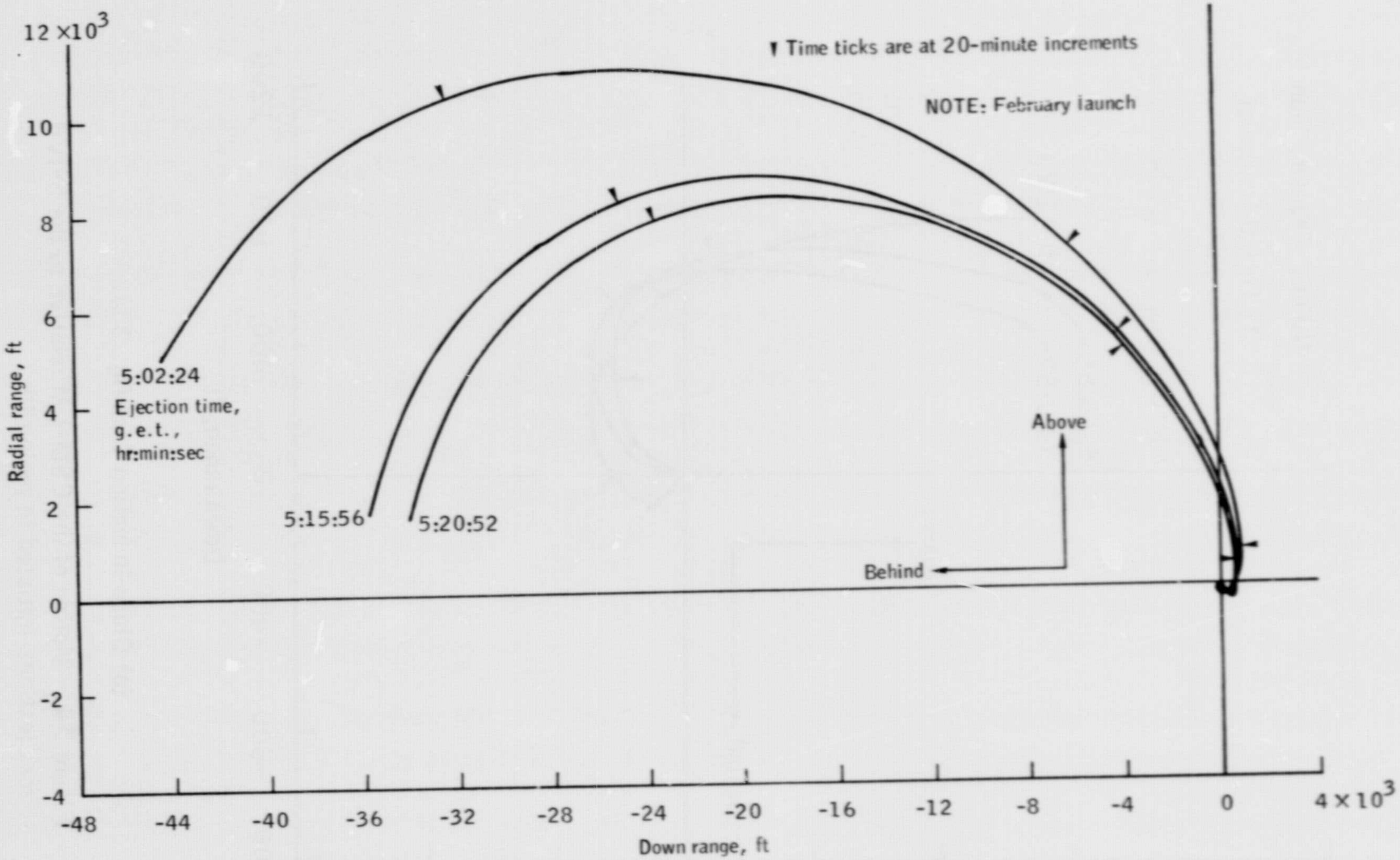
(b) Long-range motion (see fig. 31).

Figure 33.- Concluded.



(a) Close-in motion (see fig. 31).

Figure 34.- Motion of the CSM/LM relative to the S-IVB for ejections initiated in region III.



(b) Long-range motion (see fig. 31).

Figure 34.- Concluded.

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